A TEXT-BOOK

ON

ROADS AND PAVEMENTS

BY

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PREFACE.

SUCCESSFUL practice in the construction of highways must depend upon correct reasoning from elementary principles in each instance rather than upon following definite rules or methods of construction.

The aim of this book is to give a brief discussion, from an engineering standpoint, of the principles involved in highway work, and to outline the more important systems of construction, with a view to forming a text which may serve as a basis for a systematic study of the subject.

Details and statistics of particular examples have for the most part been excluded as undesirable in a book of this character. Such information is available in many forms for those having the necessary elementary training and experience to enable them to properly use it.

Considerable space has been given to the location and construction of country roads, as seemed proper in view of the present general public interest in the matter, and the probable development of this new field of activity in engineering work. The improvement of our common roads must come through transferring such work to the charge of those who make it a profession, and not through teaching the public how roads should be constructed.

F. P. S.

ITHACA, N.Y., July, 1894.

NOTE TO FOURTH EDITION.

DURING the past few years, advances in the methods employed in the construction and maintenance of highways have been very rapid. Changes in the character of traffic, due to the introduction of automobiles, have presented new problems, while modifications in the standards of life, both in city and country, render the old methods no longer satisfactory to the public. These changed conditions have caused more careful and scientific study of materials, and resulted in the use of more efficient methods, and in the development of new types of construction.

In preparing the third edition, in 1908, it was found necessary to practically rewrite the entire book. In the present edition, new chapters are added on Bituminous Macadam and Concrete Pavements, while the chapters on Brick, Asphalt and Wood Pavements have been considerably modified. The size of the book has necessarily expanded considerably beyond its former limits.

F. P. S.

COLUMBIA, MO., June, 1912.

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ROADS AND PAVEMENTS.

CHAPTER I.

ROAD ECONOMICS AND MANAGEMENT.

ART. 1. OBJECT OF ROADS.

THE primary object of a road or street is to provide a way for travel, and for the transportation of goods from one place to another. The facility with which traffic may be conducted over any given road depends upon the resistance offered to the passing of vehicles by the surface or the grades of the road, as well as upon the freedom of movement allowed by the width and form of the roadway. In order that a road may offer the least resistance to traffic, it should have as hard and smooth a surface as possible, while affording a good foothold to horses, and should be so located as to give the most direct route with the least gradients.

The expediency of any proposed road construction or improvement depends upon its desirability as affecting the comfort, convenience, and health of residents of the locality, and also upon its economic value, which is largely determined by its cost and durability, as well as upon the facility it gives for the conduct of traffic.

The desirability of a road surface for any particular use depends both upon its fitness for the service required of it and upon its durability in use.

Upon a country road, the problem of improvement ordinarily consists simply in providing the hardest and most durable surface consistent with an economical expenditure of available funds, the object being to lighten the cost of transportation by reducing the resistance to traction, and to render travel easy and comfortable.

Upon city streets, however, several other factors may be of importance in the design of highway improvements.

The comfort both of those using the street and of the occupants of adjoining property will be largely affected by the freedom of the surface from noise and dust.

The safety of the pavement in use, its effect upon the health of residents of the locality, and its economic value must in each case be considered.

To adjust to the best advantage these various elements, frequently quite discordant with each other, is a matter which can only be accomplished by the exercise of good judgment. Local conditions and necessities must always be considered — such as the difficulties of drainage, the availability of various materials, the nature of the traffic to be carried, and the needs of the business or property interests of the neighborhood. Thus, for heavy hauling of a large city, the durability and resistance to wear of the pavement may be the paramount consideration; for an office district, quiet may be very important; for the lighter driving of a residence street, the elements of comfort and healthfulness may properly be considered as of greater force than the purely economic ones; while in all of the cases the necessary limitation of first cost will largely determine what may or may not be done.

The problem of the highway engineer, in designing works of this character, involves the consideration of these various elements and their proper adjustment to give the best results.

The kinds of road surface most commonly employed are as follows: For the streets of cities and towns, pavements of stone blocks, brick, asphalt, and wood; for suburban streets and important country roads, macadam and gravel surfaces; for ordinary country roads in general, surfaces of earth or gravel.

ART. 2. RESISTANCE TO TRACTION.

The resistance to traction of a vehicle on a road surface may be divided into three parts: axle friction, rolling resistance, and grade resistance.

Axle friction varies with the nature of the bearing surfaces, and for vehicles of similar construction is directly proportional to the load. It is entirely independent of the nature of the road surface.

Rolling resistance is of two kinds: that due to irregularities in the surface of the road, and that of a wheel to rolling upon a smooth surface, sometimes called rolling friction.

The resistance due to an inequality in the road surface is the horizontal force necessary, at the axle, to raise the weight upon the wheel to the height of the obstacle to be passed. Thus (Fig. 1), by the principle of the lever, $P = W \frac{c}{a}$.

For small inequalities, this resistance will be approximately inversely as the diameter of the wheel. The effect of small irregularities in the surface, however, is due more to the shocks and concussions produced by

them than to the direct lifting action of the obstacle, and the resistance due to uneven surface is greater at high than at low velocities.

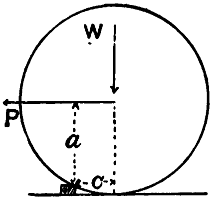


FIG. 1.

Rolling friction is probably due for the most part to the compressibility of the surface of the road, which permits the wheel to indent it to some extent. The wheel is thus always forcing a wave of the surface before it, or climbing an inclination caused by its weight upon the road surface.

Size of Wheels. — The resistance to traction varies for wheels of differing diameters, being less for large than for small wheels. The experiments of M. Morin, in France, seemed to indicate that the resistance varies inversely as the diameter. Other experiments have indicated a less variation, approximately as the square root of the diameter, while Mr. D. K. Clark (Roads and Streets, by Law and Clark; London, 1890) concludes, from a mathematical discussion based upon the assumption that the material of the surface is homogeneous and the pressure proportional to the depth of penetration, that the resistance to traction is inversely as the cube root of the diameter of the wheel. The experiments of Mr. Mairs (Bulletin, University of Missouri Agricultural Experiment Station, 1902) indicate that tractive resistance is somewhat less with large than with small wheels, being nearly inversely as the square root of the diameter, but as might be expected, differing somewhat for different road surfaces.

For practical purposes it may be considered that, for wheels of ordinary sizes used on road vehicles, the

rolling resistances are equal to the load multiplied by a coefficient which depends upon the nature and condition of the road surface, although these coefficients are somewhat affected by the sizes of the wheels.

Width of Tire. — The effect upon tractive resistance of the width of tire upon the wagon wheels depends upon the character of the surface upon which the wheel is rolling. In a series of experiments at the University of Missouri Agricultural Experiment Station in 1897, it was found that wide tires considerably diminished tractive resistance upon broken stone and gravel roads, and upon earth roads in good condition, but upon muddy roads or when a hard road is covered with deep dust the resistance is greater for wide tires. The wide tire also has considerable advantage upon plowed land or sod, not cutting in so deeply.

Speed of Travel. — Tractive resistances are somewhat greater at high than at low velocities. This difference is very slight on earth roads in good condition or on smooth pavements; but on rough pavements where concussions take place the resistance increases rapidly as the speed becomes greater.

Road Surface. — Many experiments have been made for the purpose of determining the tractive force required for a given load upon various road surfaces. The results show somewhat wide variations, as would be expected when the many elements that may affect them are considered. The following table shows a few average results, which will give some idea of the relative resistances of various surfaces and of the advantage to be derived from a smooth and well-kept road surface:

TRACTIVE RESISTANCES ON VARIOUS SURFACES.

Character of Road.	Resistance per Ton, Pounds.
Earth Roads — in fair condition	100 to 175
dry and hard	60 to 125
Macadam — very good	25 to 50
ordinary	40 to 100
poor	75 to 150
Granite block pavement — good	25 to 50
ordinary	40 to 80
Brick pavement	20 to 50
Wood block pavement	25 to 50
Asphalt pavement	20 to 70

The resistance upon asphalt is greater at high than at low temperatures.

Grade Resistances. — Tractive resistance due to grade is independent of the nature of the road surface or of the size of the wheels. It is equal to the load multiplied by the sine of the angle made by the grade with the horizontal. Thus in Fig. 2 the tractive force P, due to the grade, is the force necessary to prevent the wheel from rolling down the slope under the action of the weight W, or it is the component of W parallel to the slope ac.

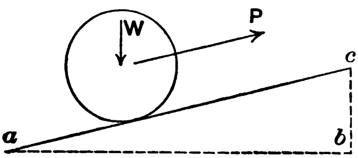


FIG. 2.

$$\therefore P = W \frac{bc}{ac}.$$

Grades are ordinarily expressed in terms of rise or fall in feet per hundred, or as percentage of horizontal distance.

For all ordinary cases of small inclinations *ab* is approximately equal to *ac*, and we may take

$$P = W\frac{bc}{ab};$$

or the tractive force necessary to overcome any grade equals the load multiplied by the percentage of grade.

The total tractive force necessary to haul a load up an inclined road equals the sum of the force necessary to haul the load upon the same surface when level and the force necessary to overcome the grade resistance. Thus, if we wish to find the tractive effort necessary to haul a load of 2 tons up a grade of 3 ft. in 100 over a good macadam road. Taking the resistance of the road surface when level at 60 lbs. per ton, we have for the total resistance

$$R = 2 \times 60 + 4000 \times \tfrac{3}{100} = 240 \text{ lbs.}$$

In going down the grade, the force due to grade becomes a propelling force, and the tractive effort required is the difference between the surface resistance and grade force. In case the grade force be the greater, the resulting tractive force becomes negative, or it will be necessary to apply the force as a resistance to prevent acceleration of the velocity in the descent.

The angle for which the tractive force required for a given surface equals the grade resistance is called the *Angle of Repose* for that surface. In the case given above, $2 \times 60 - 4000 \times \tfrac{3}{100} = 0$, or the angle of repose for a surface whose level resistance is 60 lbs. per ton is a 3 per cent grade. If a vehicle were left standing upon that inclination, it should remain standing with the forces just balanced. If it were started down the grade, it should continue to move at a uniform rate, without the application of any other force.

ART. 3. TRACTIVE POWER OF HORSES.

The loads that a horse can pull upon various road surfaces will not necessarily be proportional to the resistance offered by the surface to traction, as the tractive force that the horse can exert depends upon the foothold afforded by the surface. The ability of a horse to exert a tractive force depends upon the strength of the animal, upon his training for the particular work, and whether he be accustomed to the surface upon which he is travelling. The work of different animals is therefore subject to considerable variations, and only very rough approximations are possible in giving average values of the work a horse may do under differing conditions.

The tractive force that may be exerted by a horse, at moderate speeds, varies approximately inversely as the rate of speed; or, in other words, the power that a horse can exert through any considerable time is nearly constant for varying velocities. Thus it may be assumed, as an average value, that a horse working regularly ten hours per day can put forth a tractive effort of 80 pounds at a speed of 250 feet per minute on an ordinary level road surface.

For the power of the horse we then have

$$\text{Power} = \text{force} \times \text{velocity} = 80 \times 250 = 20000 \text{ foot-lbs. per minute.}$$

For any other rate of speed, as 200 feet per minute, we would have $20000 \div 200 = 100$ pounds as the tractive force exerted by the horse.

If the period of daily work be lessened, the power that may be developed will be increased, either by increasing the load or the velocity.

The tractive force that a horse is able to exert decreases very rapidly as the rate of inclination increases. This is due both to the expenditure of power by the horse in lifting his own weight up the grade, and to the less firm footing on the inclination. The effect of differences in the foothold afforded by various pavements is very marked in the loss of tractive power upon grades.

In the table below are given the loads that an average horse may be expected to continuously haul up different inclinations, on various road surfaces, at slow speed. These figures, while of little value as an absolute measure of what may be done in any particular case, are of use as a rough comparison of the relative tractive properties of different surfaces and grades. The effect of grades upon tractive effort will also depend upon the condition in which the surface is maintained, and upon the weather. Snow and ice in winter, or the damp and muddy condition of some pavements in wet weather, have a very considerable effect to diminish tractive power.

LOADS IN POUNDS THAT A HORSE CAN DRAW UPON VARIOUS SURFACES AND GRADES.

Kinds of Surface.	Rate of Grade.							
	Level.	1 in 100.	2 in 100.	3 in 100.	4 in 100.	5 in 100.	10 in 100.	15 in 100.
Earth road — good........	3000	2400	2000	1600	1400	1200	800	300
poor........	1300	1100	900	700	600	500	400	150
Broken-stone — good	4000	2700	2000	1600	1400	1200	700	200
poor......	1600	1100	800	600	500	450	250	100
Stone Blocks — good	6000	4500	3300	2700	2200	1700	900	400
poor.......	3000	2300	1700	1400	1100	900	450	200
Asphalt — clean and dry...	8000	4000	2500	1800	1300	1000	400	....

In general, the tractive effort that a horse may exert is approximately proportional to the weight of the horse and the averages above given correspond to light animals; many horses are capable of exerting double the pull mentioned.

A horse may frequently exert for a short time a tractive force about double that which he can exert continuously; hence, when short grades occur steeper than the general grades of the road, loads may often be taken over them much heavier than could be carried if the steeper grade prevailed upon the road.

On ordinary country roads in dry weather the amount of load that can be hauled is usually determined rather by the grades than by the nature of the surface. Unless the gradients are very light the amount of load that can be carried on a broken-stone surface does not differ greatly from what may be taken on a dry and hard earth road. In improving a road by substituting a hard surface for a surface of earth the gradients and location should therefore always be carefully studied, with a view to deriving the full practical benefit from the hard surface in the light traction that it may require with easy ruling gradients.

ART. 4. BENEFITS DERIVED FROM GOOD ROADS.

The condition of the public highways is a matter of the most vital interest to any rural community. Upon it depends largely the social life and enjoyment of the people living in the country as well as the ability to market the products of the farm to the best advantage.

In nearly all parts of the country the roads are fairly good during a portion of the year; but there is also usually a period when they are very bad, in very

many localities becoming practically impassable. The improvement of the road surfaces and the use of systematic maintenance would make the roads better at all times, making it possible to haul larger loads over them and rendering them more pleasant to travel; but the most important object of road improvement is to eliminate the period when roads are not in condition to use and make it possible to drive upon them and haul loads over them at all times.

The benefits of good roads may be classified as social, educational, and financial. They promote social intercourse among the residents of a country district by making travel easy and pleasant. Where the roads become impassable during a portion of the year, the residents are practically isolated at the period of greatest leisure and lose that intercourse with their neighbors which is a most important means of enjoyment and development. Attendance at church and public meetings is facilitated by good roads. There are many localities where the condition of the roads practically closes the churches during a considerable portion of each year, and in some instances they have been so deserted on this account as to be abandoned. The rural mail delivery also depends for its efficiency upon the good condition of the roads.

The consolidation of rural schools and establishment of rural high schools, made possible by good roads, is an important advance in educational methods, and places rural communities more nearly on an equality with the cities in educational advantages offered to children.

Roads which can be traveled all the year admit of marketing the products of the farm at any time which may be most advantageous, enabling the farmer to take

advantage of favorable market conditions and prices, or to transport his products at a convenient season, when he can do the work without interference with other duties of men and teams.

The condition of the highways has also considerable effect upon the business of the towns into which they may lead; where they are uniformly good throughout the year mercantile business will be better distributed between different seasons, and a larger volume of business will be transacted. The same effect is produced upon railway transportation. Congestion in railway business and scarcity of cars is frequently the result of the hurried marketing of crops to take advantage of a good condition of the wagon roads, and a much better distribution of business might be obtained through an improved condition of the highways. The area tributary to a town or a railway may also frequently be considerably extended by road improvement.

The greatest benefits derived from good roads are in the increased comfort, convenience, and pleasure of the people living near them, and in the social and educational advantages which they make possible and which add greatly to the attractiveness and happiness of rural life.

ART. 5. COST OF WAGON TRANSPORTATION.

The effect of bad roads upon the cost of wagon transportation has been the subject of much discussion and many estimates have been made which have arrived at widely different conclusions. Many of these discussions have failed to take account of all the factors entering into the problem and have arrived at

wildly extravagant results. Efforts have been made by the Road Inquiry Office of the United States Department of Agriculture to collect statistics concerning the volume and cost of hauling farm produce to market for the whole United States. These statistics include estimates of the average length of haul and the cost per ton-mile, with a view to basing upon them some conclusion as to the saving to the country in general which would result from the improvement of the roads so that larger loads may be carried, and less labor be required for moving the crops. Statistics of this kind are very difficult to gather, being altogether dependent upon the judgment of the man who collects them in each locality, and representing only very approximately the average conditions. They are of value as giving information concerning the traffic to which the roads are subject in various localities and the need for road improvement, but they do not contain data upon which any reasonable estimate can be based of the actual saving which might be effected by road improvement. Such general estimates are not of any particular value other than that of showing something of the size of the problem when applied to the whole country.

Many palpably erroneous and exaggerated estimates of the saving in cost of transportation by road improvement have been published and have often seriously injured the cause of good roads. They aim to show the large saving which may be effected by the farmer through reducing the cost of moving his crops to market, but their fallacies are evident to the farmer who reads them and applies them to his own conditions, and in many instances lead him to doubt the good faith of the whole movement for good roads. These estimates commonly treat the subject as though the

whole of the crops were hauled to market in full loads by teams kept by the farmers for that purpose alone, and which could be dispensed with if the roads were so improved as to require a less number of loads, and consequently less teams to transport the crops, which is clearly not the case.

The effect of the condition of the highways upon the cost of wagon transportation depends upon the character of the traffic. Where this consists of the transportation of some product which is hauled in full loads, with teams which are employed for this purpose only, the cost of transportation is readily ascertained, and the saving due to any improvement which increases the load carried by each team may be found by estimating the cost of the decreased number of teams required. If an earth road in poor condition be replaced by a good macadam surface, the load which can be taken over the road may easily be doubled if upon light gradients, while where a traffic of this character must be taken over an earth road in bad or muddy condition, the construction of an improved road surface may result in loads four or five times as heavy as before. In this case the number of teams is inversely proportional to the maximum load which may be hauled and the cost is proportional to the number of teams. This condition soemtimes, though rarely, occurs upon wagon roads, the traffic usually being of a mixed character, with varying percentages carried in full loads, and with teams kept for other purposes and only incidentally used for transportation upon the roads.

For the purpose of estimating the cost of transportation upon ordinary country roads it is necessary to separate the traffic into classes and determine what

portion of it is carried in full loads. This is always a matter of difficulty where the traffic is varied and can only be done in a very roughly approximate manner. The light portion of the traffic will, of course, be benefited by improved roads, but the saving in cost of conducting the traffic, while existent, is usually comparatively small and practically indeterminate. It consists in saving time of men and teams through greater speed of travel, and in less wear upon teams and vehicles. When such traffic must be conducted over muddy and bad roads these items may be of considerable importance, although they can not be evaluated, but commonly they are of slight importance.

The heavy portion of the traffic is more directly affected by the character of the roads over which it passes. This traffic is carried in full loads, which are limited in amount by the condition and gradients of the roads. In some localities this constitutes the main portion of the traffic; in others it is a comparatively small part of the whole. No generalization concerning the value of road improvement as reducing the cost of transportation can therefore be made with any approach to accuracy; but in a particular instance where data is obtainable concerning the heavy traffic, it is possible to roughly estimate the saving in labor of transportation through road improvement. If we can determine the cost of using teams for this purpose, an approximate estimate may also be made of the saving in cost of transportation through such improvement. The cost of using teams for highway transportation is often difficult to obtain on account of the fact that such teams are commonly kept for other purposes and only incidentally used for road work,

and in some instances it is possible that the transportation is done when there is no other work which could be done by the team. In general, however, it is fair to assume that the cost of the work is proportional to its amount, and that if the teams were not employed in transportation on the highway, they would be otherwise usefully engaged. In estimating the cost of work of teams, the actual cost to the farmer of keeping the team should be used and not the rental value of teams in the vicinity.

A careful examination of the local conditions surrounding the traffic is essential to any reasonable estimate of saving to be effected in cost of transportation upon highways. Such estimates are not of much value at best as giving actual amount of savings, but studies of this kind may be of value in giving a better conception of the economics of the good roads problem.

Art. 6. Economic Value of Road Improvement.

The value of a road improvement to a community and the amount of money that may reasonably and profitably be expended in the construction and maintenance of common roads is a subject the discussion of which leads different persons to widely different conclusions, depending upon the point of view and the data assumed. Any improvement, either in position or surface, that has the effect of increasing the loads that may be taken over a road by a given power lessens the number of loads necessary to carry the traffic, and effects a saving in time and labor of men and teams, which may reasonably be considered to have the same

money value as the time used in the work. This has been discussed in Art. 5 and is the most direct and obvious financial gain which may result from road improvement.

Saving in cost of transportation is not, however, the most important advantage to be gained by road improvement, and if it were the only one, in many instances, the expenditure of money necessary to secure better roads could not be justified as economically profitable.

It is in wet and muddy weather that improved surfaces have their chief advantage over earth roads, and the main object of introducing hard and impermeable surfaces is to eliminate the period when ordinary earth roads are apt to be muddy and practically useless for the purposes of transportation, and to substitute a road that may be used at any season. Systematic drainage has a similar object. To a farming community the economic advantage of a road uniformly good at all seasons is greater than might appear at first glance. It may in many instances amount practically to a saving equal to nearly the entire cost of hauling by permitting the work to be done at times when other work is impossible, thus making men and teams available for other duty in good weather. The ability to use a road at any season is also of advantage in the independence of weather that will make it possible to take advantage of the condition of the markets in the disposal of produce or purchase of supplies. These advantages may be of greater or less importance according to the character of the traffic carried by the road. In general, while they are indeterminate and can not be expressed in money value, they are evidently of more economic

importance than the saving effected in costs of transportation.

The nature of the country roads affects the towns to which the country is tributary as well as the country itself. They directly affect trade in seasons of bad weather, both in regulating the demand for supplies for country consumption and in controlling the supply of produce which is available for market; indirectly also the prosperity of a rural district means that of its trade center. The improvement of country roads is, therefore, of direct economic value to towns into which they may lead, but this, like most of the other advantages of good roads, is dependent upon data which can not be accurately estimated.

All of these points must be considered in any attempt to arrive at any proper conception of the advantages of a proposed improvement. In any particular case the local interests will determine the relative importance of the various elements, and a careful analysis of the trade that does pass over the road and that would pass over it under different conditions will enable a judgment to be formed as to the value of improvements. The attempt to base an estimate of the economic value of a proposed road improvement upon the prospect of direct financial return is, however, apt to be misleading and to leave out of account the most important benefits of such improvements. The social and educational benefits mentioned in Art. 4 are of highest importance and have also an economic value in their effect upon the desirability of a locality as a place of residence. The economic importance of good roads is shown in their effect upon land values, which are largely affected by them.

The money spent in road improvement is to be

considered as an investment, which will return annual interest to the community in reduced costs of transportation, greater freedom of traffic and travel, and in the increased comfort and happiness of the people.

ART. 7. SOURCES OF REVENUE FOR ROAD CONSTRUCTION.

Various methods have been employed for securing the funds necessary for the construction and improvement of country roads. Many of the earlier roads in this country were toll roads built by private capital and kept up exclusively by charges paid by travelers. Toll roads are objectionable because they impose a tax upon all the traffic of the road, and also because the cost of management is usually large, thus restricting traffic. They are conducted for the purpose of deriving a profit from their operation. They are gradually disappearing and should be dispensed with except under exceptional circumstances.

District Roads. The most common method of raising funds for road purposes is by property and poll tax in small districts. By this method a small poll tax is assessed against each voter of the district, payable either in money or labor, and a certain property tax which is levied uniformly upon property in the district, and often also payable in labor or cash at the option of the property owner. In some instances the property tax must be paid in money, and in others a portion of it must be paid in money. In some poor and sparsely settled localities the poll tax is the principle source of revenue, and road work consists mainly in working out the road tax by the residents of the district.

As a general thing, the results of the collection of road tax in labor are not good. Under the labor system men do not work on the roads a sufficient length of time to become expert enough to do good work; many of them feel no particular interest in the work and are only concerned in getting in the required time. Under this system it is not usually possible to have the road work done when it is needed, as the convenience of the laborers must be considered. In many places therefore efforts are being made to require the payment of property tax in money. This is highly desirable wherever the money will be expended under proper management, but in numerous instances no improvement has followed a change to the cash system because of a lack of intelligent control of the work.

County Road Tax. In some states there is a general property tax for road and bridge purposes. This tax is, usually, at the disposal of the county commissioners, or county court, which uses it for the construction and maintenance of county bridges and also for such road work as may be of special importance and of interest to the county in general. Frequently such funds are used to encourage the construction of improved roads by paying a part of the cost where owners of property specially benefited, or road districts in which the road may lie, are willing to pay their share of the cost. The maintenance of the ordinary country roads usually depends upon the district tax, but a county road fund judiciously administered may do much to improve the more important highways and thus secure good roads leading from various parts of the county to the market towns.

Special Assessments. The laws of some of the states provide for levying special assessments against property benefited by the improvement of country roads. These laws are usually permissive, allowing either the county court or majority of property owners concerned, by instituting proper proceedings in court or before commissioners, to have the improvement made and assessed upon property within certain distances from the road. In some instances the whole cost is paid in this way; in others a part is appropriated by the county, or state, or both, and a part is raised by special assessment.

State Appropriations. Several of the states appropriate state funds, which may be used in assisting in the construction of improved roads throughout the state. The amount of assistance given varies in different states; in New Jersey 33⅓ per cent of the cost is paid by the state, 56⅔ per cent by the county, and 10 per cent by the abutting property; in Massachusetts the state pays 75 per cent, and the county 25 per cent; in New York the state pays 50 per cent, the county 35 per cent, and the town 15 per cent.

These various laws all have for their object the distribution of cost upon all interests benefited by the work. There has been much discussion of this subject and many opinions expressed concerning the justice of various methods of distributing the cost. The improvement of main roads by local districts without outside assistance does not seem equitable, and the use of general county tax for this purpose is intended to place a share of the cost upon the towns and other interests not reached in the local taxes. It also secures a centralized and usually better control of road work. All of the sources of revenue are

benefited by road improvement and may reasonably be expected to contribute to its cost, but the exact evaluation of relative benefits is not possible, and the amount each must pay should be determined by considering what is feasible and in what way the greatest improvement may be effected.

ART. 8. SYSTEMS OF ROAD MANAGEMENT.

Several different systems for managing the work of constructing and repairing country roads have been proposed or are in use in various places. These systems differ in the placing of the control of the roads and in the methods adopted for providing funds.

The control of the roads under the various systems may be vested in the national government, in the various State governments, in county or parish organizations or in townships or districts. In regard to the location of control and responsibility, it may be remarked that there are two points to be kept in view.

1st. In order that the work may be economically conducted, the section of country included under one control should be sufficient to warrant the permanent employment of a man, or corps of men, whose business it shall be to continually look after the roads, study their needs, and systematically conduct their improvement. It should admit of the ownership and use of labor-saving machinery for the economical execution of the work, but should not be large enough to require an elaborate and complicated organization.

2d. The control of road work should be so arranged that, as nearly as possible, all of the interests directly affected by the condition of any road shall have a voice in its management and contribute to its support.

Common roads are essentially local in their character and are not usually employed as lines of continuous transportation over any considerable distance. They are not, therefore, of state or national importance as lines of communication, although as factors in the general welfare of the people they must, of course, like all other such factors, be of general interest and concern to both state and nation.

The nation, and in most cases in this country the state, is too large a unit to assume direct control of road work. In general, the interests over so large an area are so varied, and the requirements so different, as to prevent a harmonious and successful organization of such work with a probability of economical administration. In some cases, however, such control might be wise and proper, and the recognition of the importance of road improvement to the general welfare of the state, through the payment by the state of a portion of the cost of permanent improvements, has in some instances proved a powerful stimulus to local action.

The control of road management by towns and small districts is nearly always inefficient because the organization is too small to support a proper management or provide the necessary appliances for economic work. Under this system the man in charge of the roads is usually engaged in other work; he is not a road engineer, and can, and is expected to, give but little attention to the road work. This system of control is also usually unfair, except in case of roads intended for the accommodation of the local district only. For instance, a road passing through a town may be a thoroughfare for the towns upon each side. The principal traffic may be this through-trade to points beyond the limits

of the town in which the road is situated. The cost of keeping up this road is largely due to outside traffic, and the intermediate town should not be required to bear all the expense of maintenance. On the other hand, the interests of the towns whose trade passes over the road are largely affected by its nature, and the people of these towns should be permitted a voice in determining the character of the road. Most of the more important roads of every vicinity pass thus through several towns, and the system of improvement by small districts works injustice both ways — upon those who are obliged to keep a road for the use of others and upon those who are obliged to use a road they cannot cause to be kept in proper condition.

County management seems more successful in this country than any other, as a county, or two counties combined if necessary, is usually strong enough to secure intelligent management and homogeneous enough to have common interests.

The proper management of the common roads in any community requires both experience and intelligence. A man to be efficient in such work must be able to make or modify location where necessary, judge of the value of various materials for purposes of construction, determine the necessity for and means to be adopted for drainage, and possess the executive ability to manage men and control scattered work. The work in each locality is a problem by itself, to be solved by careful study of the requirements of the community, taking into account the local natural conditions and available materials and means.

Several of the states have State Highway Commissions, or State Highway Engineers, for the purpose of promoting the improvement of the country roads.

These commissions are usually mainly advisory in character. They investigate and report upon the condition and needs of the roads, advise the local authorities concerning the best methods of construction, furnishing plans and specifications if desired, and control the expenditure of state funds applied to road purposes. These commissions have accomplished much in the way of improving existing conditions in several states, and have done much toward creating sentiment favorable to the expenditure of funds for such work.

In Missouri the new road law provides a combined county and district management. It creates the office of County Road Engineer to be appointed by the county court. The County Engineer has direct charge of the expenditure of the general county road and bridge fund, and all district road supervisors in the county are required to report to him and to conduct their work under his general direction. The purpose is to provide a competent central authority in each county, without changing the existing division into road districts. There is also a State Highway Engineer whose duties are to advise with the local authorities, and to distribute and control the expenditure of state appropriations in aid of road improvement.

CHAPTER II.

DRAINAGE OF ROADS AND STREETS.

ART. 9. NECESSITY FOR DRAINAGE.

THE road-bed, usually formed of the natural earth over which the road or pavement is to be constructed, must always carry the loads which come upon the road surface. Where an artificial road surface or pavement is employed, the earth road-bed is protected from the wear of the traffic, and the wheel loads coming upon the surface are distributed over a greater area of the road-bed than if the loads come directly upon the earth itself; but the loads are transferred through the pavement to the road-bed, and not sustained by the pavement as a rigid structure.

The ability of earth to sustain a load depends in a large measure upon the amount of moisture contained by it. Most earths form a good firm foundation so long as they are kept dry, but when wet they lose their sustaining power, becoming soft and incoherent. When softened by moisture the soil may be easily displaced by the settling of the foundation of the road, or forced upward into any interstices that may exist in its superstructure.

In cold climates the drainage of a road is also important because of the danger of injury from freezing. Frost has no disturbing effect upon dry material, and hence is an element of danger only in a road that retains water.

In order, therefore, that the loads may be uniformly sustained, and the surface of the road kept firm and even, it is evidently of first importance that the road-bed be maintained in a dry condition. The improvement and maintenance of a road are therefore largely questions of drainage, the object being to prevent water from reaching the road and to provide means for immediately removing such as does reach it before the soil becomes saturated and softened.

Surface drainage is always necessary if the body of the road is to be kept in a dry condition, and is accomplished by having the surface of such form that water falling upon it will quickly run into the gutters.

The necessity for underdrainage in any case depends upon local conditions, the nature of the soil and the tendency of the site to dampness. Underdrains are for the purpose of lowering the level of ground water in wet weather and preventing water from underground sources reaching the road bed and softening it. A careful examination of local conditions is necessary in any case to determine the advisability of constructing underdrains. Where the soil upon which the road is constructed is so placed that the ground water is at any time likely to stand close to the surface and become soft immediately under the road-bed, underdrainage is necessary to good results in the maintenance of the road. In any case in which the level of ground water stands within about 3 feet of the surface, the road will be benefited by sub-surface drainage, although it may not be altogether necessary to the maintenance of the road. Underdrainage is of little use for the removal of water from depressions in the surface of the road.

Art. 10. Surface Drainage.

The drainage of the surface of a road is provided for by making the section higher in the middle than at the sides, with ditches or gutters at the edges of the road along which the water is conducted until it may be disposed of through some side channel.

The slope necessary from the middle to the sides of the road to insure good drainage depends upon the nature of the road surface, being less as the road surface is more smooth and less permeable to water. For ordinary earth roads it varies from about 1 in 10 to 1 in 20; for macadam or gravel roads, from 1 in 15 to 1 in 30; and for brick or asphalt pavements, from 1 in 40 to 1 in 60.

The drainage of the surface of a country road is mainly a matter of maintenance, and involves keeping the surface of the road in a smooth condition and properly crowned. It is more fully discussed in Arts. 25 and 27.

On country roads the disposal of surface water is not usually a matter of difficulty, as it can be carried along the road and run into the first convenient cross channel. In deep cuts or on steep grades, however, it may sometimes be economical to lay a pipe under the gutter into which surface water may be turned at frequent intervals.

In all cases it is important that the water which falls upon the surface should be gotten rid of as soon as possible, for so long as it remains upon the road it is an element of danger, both from its tendency to wash the surface, and from its liability to penetrate into the road and thus cause disintegration or settlement.

ART. II. SUBDRAINAGE.

The drainage of the subsoil under a road is intended to lower the level of ground water in wet weather and prevent water from sub-surface sources reaching the road-bed.

The necessity for subdrainage, and the method to be employed in any case, depends upon whether the soil over which the road is being constructed is naturally wet or dry, and whether the road-bed is so situated and formed as to give it natural drainage.

The material of which a road-bed is composed is important because it determines to a large extent whether artificial drainage is necessary, and also what method should be adopted for securing drainage.

Soils differ in their power to resist the percolation of water through them, in the rapidity and extent of their absorption of water with which they come in contact, in the extent to which moisture renders them soft and unstable, and in their power of retaining moisture.

A light soil of a sandy nature usually presents little difficulty in the matter of drainage, as, while it is easily penetrated by water, it is not retentive of moisture, which passes freely through it without saturating it unless prevented from escaping.

If the natural drainage, therefore, have a fall away from a road-bed formed of such material, it will usually need no artificial drainage, and where subdrains are necessary they may be relied upon to draw the water from the soil to a considerble distance each side of the drain.

A nearly pure sand is more firm and stable, under loads, when quite damp than if dry, although a fine sand saturated by water which is unable to escape may become unstable and treacherous.

Clays usually offer considerable resistance to the passing of water through them, and are very retentive of moisture. As a rule, however, a clay soil does not absorb water readily, and requires that water be held for some time in contact with it in order that it may become saturated, although when saturated it is the most unstable of soils. A clay that when dry will stand in a vertical wall and support a heavy weight, when wet may lose all coherence and become a fluid mass. When water comes in contact with a bed of such clay, the outside becomes saturated and semi-fluid before the moisture penetrates into it sufficiently to even moisten it a few inches from the surface.

A clay soil is, therefore, always difficult to drain by removing the water after it has soaked in, or by permitting it to pass through the road-bed to the subdrains beneath. Drainage, in such cases, may often be so arranged as to prevent water from standing against the road and thus prevent it from becoming saturated. As the clay is comparatively non-absorptive, the water which may come upon its surface, if allowed to escape at once, will not penetrate into it, and hence will not cause softening.

A heavy silt formation is sometimes met with which is even more difficult to drain than a true clay. It is nearly as retentive of moisture as a clay, strongly resisting the passage of water through it, but at the same time absorbs water quite freely when in contact with it.

Between the extremes mentioned above there are a great number of varieties of soil which possess to a greater or less extent the characteristics of either or both, and gradually merge the one into the other. In applying a system of drainage in any case, careful

attention should always be given to the characteristics of the soil, as determining very largely the treatment to be used.

Where artificial subdrainage is necessary the drains should be located, in so far as possible, with a view to cutting off the supply of water before it reaches the road-bed. To accomplish this to the best advantage the local conditions must be observed, the sources of this supply determined, and the nature of the underflow, if any exist, considered. In most instances on roads over soil commonly met upon country roads a single line of tile under one side of the road will lower the ground water sufficiently to prevent it reaching the road-bed.

Frequently, as in many cases of a road along a side slope, there is a well-defined flow of sub-surface water from one side to the other, and in such case the water may perhaps be intercepted by a single longitudinal drain on the side of the roadway from which the water comes. An example of this is shown in Fig. 3.

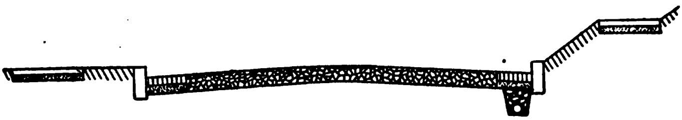


FIG. 3.

When the subsoil is of stiff and retentive material which does not drain readily, an underdrain on one side may not draw the water from under the whole width of the roadway. In this case it is advisable to use a drain on each side to cut off the water before it reaches the roadway. This may be necessary with a clay soil when the line of ground water is high.

Sometimes a single drain is laid under the middle of

the road, as shown in Fig. 4. This is, in general, an undesirable practice; the middle of the roadway is not a convenient place for the drain, and necessitates digging a trench under the roadway which is likely to give considerable trouble in the early maintenance of the road surface. In some instances however a spring of water may come up under the roadway, as in a clay spout, and when this occurs it is desirable to lay a pipe to take the water from the source of supply rather than to drain it through the soil to the side drains.

The most satisfactory and cheapest method of under-

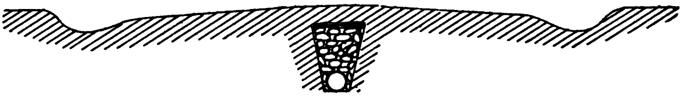


FIG. 4.

drainage is commonly by the use of porous drain tile, as used for farm drainage. Where stone is plentiful and handy to the road, a stone drain may be cheap and equally effective with the tile. These types of drains are described in succeeding articles.

Many road builders utilize the side ditches, intended for surface drainage, for underdrainage also by making them deep and narrow. This is not usually an economical practice. A tile drain and shallow gutters will not be more expensive to construct than the deep ditches, while they are much easier and cheaper to maintain. In some instances tiles are laid under the surface ditches and the trenches filled with stones, or gravel, as shown in Fig. 5, thus permitting the surface drainage to seep into the tile. This gives very effective

drainage, if the tile be of sufficient capacity, but is expensive to construct.

In considering the advisability of underdrainage and the method of accomplishing it, the fact should be kept in mind that the purpose of underdrainage is to remove ground water, and that efficient drainage of

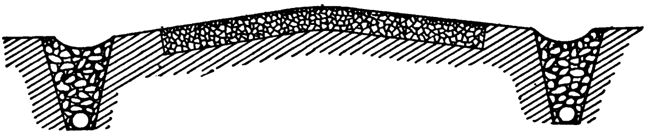


FIG. 5.

the road surface can only be accomplished by maintaining the surface in smooth condition and of proper form.

ART. 12. TILE DRAINS.

Tile drains for road drainage are constructed in the same manner as for land drainage. Ordinary porous tiles are used as in farm drainage, sizes from 4 to 8 or 10 inches in diameter being commonly employed for this purpose. They are usually in lengths of slightly more than 12 inches, the excess of length being sufficient to allow for probable breakage, so that estimates may be made on the basis of one tile to each foot of length. The tiles should be truly cylindrical with the ends cut off square, and be smooth inside. They are laid in a trench 3 or 4 feet below the surface of the ground, with their ends in contact. They should be carefully placed so that the ends fit closely, and the bottom of the trench should be cut to about the width of the tile, so that they cannot move sideways when the trench is

filled; or better still, a groove may be scooped out in the bottom of the trench to fit the tile.

Grade of Tile. The velocity of water through a tile depends upon the slope of the tile. Considerable water may be carried by a tile laid to an almost level grade. Such grades are, however, rarely necessary in road drainage and are to be avoided whenever possible. It is not desirable, except under unusual conditions, to use a grade less than about 2 inches per 100 feet. This gives a velocity which may be reasonably expected to keep the tile clear, when properly laid, except for small tiles, although a greater slope is to be preferred when obtainable.

Care should be used in laying tile to place it accurately to the grade line, particularly when the slope is light. Irregularities are apt to produce depressions in which deposit of silt may take place.

Size of Tile. A tile for road drainage should not be less than 4 inches in diameter. While a smaller tile may often be large enough to carry the water, the danger of clogging is much greater and the effect of inequalities in grade are increased for such tile. The size of tile required depends upon the quantity of water to be carried and the slope of the tile. For agricultural drainage it is common to assume that the tile must remove from ½ inch to 1 inch of water per day over the area which it drains. The rules commonly followed probably give an excessive run-off in most instances, and recent observations indicate that ¼ inch would be ample in most instances of ordinary drainage. This method may be applied in road work where the area from which the water is drawn can be determined. The area to be included depends upon the character of the soil and the way the ground lies. On level

ground the drain may be assumed to receive water from a certain distance on each side depending upon the porosity of the soil.

For road drainage the size of tile used should be such as to provide liberal capacity. Comparatively small sizes will usually be required and the differences in cost are small. An area of 25 to 50 feet on each side may be considered as contributing water to the tile. In ordinary soil the effect of the tile will reach much farther than this, but the percolation is so slow that the water will reach the tile very gradually.

This method may serve as a guide in selecting the size of tile required, but is not capable of accurate computation and is only of value as an aid to judgment. Good practice in such work must rest mainly upon the judgment derived from experience. If the tile be supposed to collect water from about 25 feet on each side, it would drain about an acre for each 870 feet of length, or about 6 acres per mile. Assuming one-half inch in 24 hours, over the drainage area, as the amount to be provided for, one acre will yield 1815 cubic feet per day, or 1¼ cubic feet per minute; and one mile of length, 50 feet wide, will yield about 7½ cubic feet per minute.

The water carrying capacity of tile drains has not been accurately determined but it probably does not greatly differ from that for vitrified pipe sewers, and the use of the formulas usually applied to sewers will be sufficiently accurate for practical purposes. The common formula for the flow of water, $v = C\sqrt{RS}$, may for our purpose be transposed into the form $V = k\sqrt{DS}$, in which V is the velocity in cubic feet per second, D is the diameter of the pipe in inches, S is the slope,

and k is a coefficient varying from about 9 for 4-inch pipe to 12 for 12-inch pipe.

The following table for the capacity of tile drains is based upon this formula. It is computed by the use of Kutter's formula, using a coefficient of roughness of .013, which corresponds to the flow in pipe sewers.

CAPACITY OF TILE DRAINS IN CUBIC FEET PER MINUTE

Slope per 100 Feet.		Sizes of Pipe.				
In.	Feet.	4 In.	6 In.	8 In.	10 In.	12 In.
2.	.67	4.	12.	27.	49.5	81.
4.	.33	5.5	16.5	38.	70.	114.
6.	.50	6.5	21.	46.5	86.5	143.
9.	.75	8.	25.5	57.5	106.5	176.
12.	1.	9.5	29.5	66.	122.5	204.
24.	2.	13.5	41.5	92.5	173.	288.
36.	3.	16.5	51.	114.	212.	353.
48.	4.	19.	59.	132.	245.	408.
60.	5.	21.	66.	148.	275.	456.

Tiles laid upon very flat slopes sometimes may carry a quantity of water greater than the capacity due to the slope; this is caused by the level of ground water standing above the tile, thus causing the water to flow in the tile under a head greater than that due to its slope. Where gravel or other porous material is available such tile will be benefited by a porous filling immediately over the tile. This also assists in keeping the tile clear of sediment.

ART. 13. STONE DRAINS.

In localities where stone suitable for such purposes exists along a roadway it is common and often economical to use stone drains for purposes of underdrainage.

Blind Drains. For short lengths, where it is only necessary to provide a permeable path for a small quantity of water to escape, blind drains may be used. They consist of ditches cut into the soil and filled at bottom with fragments of stone, the trench then filled with earth. Care should be taken that the top of the stone is protected, so that the earth may not be washed into the stone and stop the drain; a little small-sized stone or gravel on top, or a light layer of brush or sod, to hold the earth until it has compacted, is useful. Such drains have frequently proven quite efficient when used where the requirements are not too great.

Box Drains. Where suitable stone is plenty and cheap, a box drain may be built. This consists of a

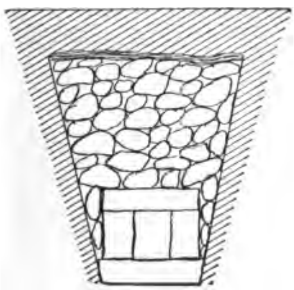


FIG. 6.

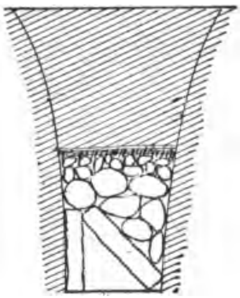


FIG. 7.

rectangular box formed of flat stones at the bottom of the trench, which is then filled with earth. This box may be very roughly built, and it is desirable when stone or gravel is plentiful to fill immediately over the drain with such material, to protect it against the entrance of earth and assist in leading the water into it. Figure 6 shows a section of such a drain as con-

structed to intercept a seepage of water in stiff retentive material. In ordinary soil there would be no advantage in filling the trench so full of stone. The construction shown in Fig. 7 is also sometimes used, and is cheap and reasonably efficient.

The size of opening in a stone drain must be considerably larger than that in a tile to carry the same quantity of water, the construction usually being very rough, and the resistance to flow greater. Drains of this type are used in many localities where materials are available for building them, although their use is growing less, due to the fact that porous tile costs so little and tile drains are so easily and cheaply constructed.

ART. 14. CULVERTS.

Culverts are commonly required in road construction for carrying under the road the small streams which may be crossed by the road, or sometimes for carrying the water collected in the gutters or ditches on the upper side of the road to the lower side.

The waterway provided by a culvert must, for safety, be sufficiently large to pass the maximum flow of water that is likely to occur, while for economy it must be made as small as may be without danger.

The maximum flow of a stream depends upon a number of local conditions, most of which are very difficult of accurate determination. These are: the maximum rate of rainfall, the area drained by the stream and its position, the character of the surface drained, and the nature of the channel.

The maximum rate of rainfall varies in different localities, and differs in the same locality from year to year. It is commonly taken at about an inch an hour.

This is sometimes exceeded for a very short time and over a small area, but is usually a safe value for a watershed of any considerable area.

The approximate area of the watershed drained by a stream is readily found, and its form is also important as determining the distance the water must flow in reaching the culvert under consideration, and to some extent regulating the rate at which the water falling upon the area will reach the culvert.

The maximum flow of a stream is also affected by the physical characteristics of the watershed. The permeability of the surface largely determines what portion of the rainfall shall reach the stream; while the slope of the surface, its evenness, and its vegetation have an effect upon the quickness and rate witn which the rainfall is received by the stream.

The determination of the maximum flow to be expected in any case from an examination of the locality is therefore possible only as a very rough approximation. A number of formulæ have been proposed for such estimation, the use of which for the case of an ordinary culvert simply amounts to estimating the quantity of water which would fall on the watershed in the heaviest probable rain, and judging as well as possible from local conditions how much of it may arrive at one time at the culvert. In some cases where a more accurate determination is desirable it may be advisable to measure the flow of the stream at high water, and form an idea from such measurement as to what may be expected at a maximum stage.

The amount of water that will pass a culvert in a given time depends upon the form of the section, the smoothness of its interior surface, its slope, and the head under which the water is forced through. A

well-constructed culvert may be considered in computing its capacity as a pipe flowing full. Other culverts or bridges must be treated as open channels.

Prof. Talbot gives (Selected Papers C. E. Club, Univ. of Illinois, 1887–8) a formula for the rough determination of area required for waterway, derived from experience:

$$\text{Area waterway in feet} = C\sqrt[4]{(\text{drainage area in acres})^3}$$

C is a coefficient depending upon local conditions. For rolling agricultural country subject to floods at time of melting snow, and with length of valley 3 or 4 times the width, $C = \frac{1}{3}$. When the valley is longer, decrease C. If not affected by snow and with greater lengths, C may be taken at $\frac{1}{5}$, $\frac{1}{6}$, or even less. For steep side slopes C should be increased.

For most cases in practice the size of waterway required may be determined from the knowledge which usually exists in the vicinity regarding the character of a stream, from the sizes of other openings upon the same stream, or from comparison with other streams of like character and extent in the same locality. Where data of this kind do not exist, careful examination of water-marks on rocks, the presence of drift, etc., may be made to determine the height to which water has previously risen. The shape of the valley and the slope of the surface is of more importance than the area of country drained. The use of a formula like Talbot's assists the arrangement of the factors which enter into the determination, and is only intended as an aid to judgment in selecting the size of opening required.

The discharging capacity of a culvert will depend upon the slope of the water surface passing through the culvert. Increasing the slope of the bed of the

culvert will increase its carrying capacity, provided the water can flow freely away below the culvert. If a culvert be so constructed as to permit the water to dam up above it, causing the culvert to flow full and under pressure, the effect is the same as increasing the slope and increases the capacity of the culvert. The velocity through a culvert is approximately proportional to the square root of the head of water, the head being the difference of elevation of the water surface at the entrance to the culvert and that where the water leaves the culvert.

There are three types of culverts in common use for road purposes: stone box culverts, pipe culverts, and concrete culverts. In some localities wooden box culverts are also used for this purpose; these are very uneconomical on account of their perishable nature and their use should be abandoned.

Stone Culverts. Culverts of stone may be either arch culverts or box culverts. Box culverts are usually formed of two side walls and a cover. The side walls consist usually of rubble stonework laid up dry or in mortar, as the case may be. Where the stream to be carried is of small importance, and the capacity of the culvert not greatly taxed, dry walls may give satisfactory results, but when the culvert is likely to flow full at certain times it should be laid up in hydraulic cement mortar, and in any case the greater stability given by the mortar would be well worth the small additional cost. Fig. 8 shows a section of the ordinary form of box culvert. The use of head walls and paving the waterway for a short distance is necessary for these, as for pipe culverts.

Where suitable stone is available, box culverts are easily constructed and economical. They are com-

monly used for openings 2 to 4 feet in width and 2 to 5 feet in height. The width that may be used depends upon the available cover stones. Where the allowable width is not sufficient to give the needed area of waterway, a double culvert may sometimes be used to advantage. This consists of two openings with a middle wall to support the covers.

The culvert's opening should always be large enough to admit of a man passing through it for the purpose

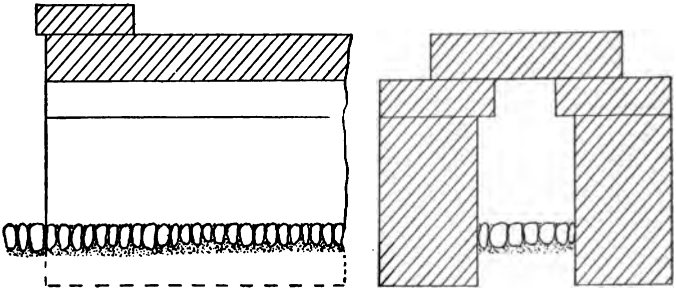


FIG. 8.

of cleaning it — at least 18 by 24 inches. The side walls should extend downward below the bottom of the culvert sufficiently to obtain a good foundation, and the thickness required for the side walls usually varies from one-half to three-fourths the height, depending upon the pressure likely to come against them.

In many cases for small work the side walls, instead of extending downward, rest upon the paving which is extended under them. This gives a somewhat less expensive construction, and is often satisfactory on good ground.

The cover stones may be from $\frac{1}{3}$ to $\frac{1}{2}$ the span in thickness, and should be long enough to have a bear-

ing upon each side wall of at least one-half the thickness of the wall.

Pipe Culverts. Pipe culverts may be constructed either of salt-glazed vitrified sewer pipe, or of iron water pipe. For culverts of sizes up to about 30 inches diameter, vitrified pipe is often the most economical material to use provided it is placed on good foundation and sufficiently covered not to be subject to shock from the traffic. The iron pipe possesses greater strength, and is preferable where a firm foundation is not easily obtained, or where a sufficient covering can not be had for the vitrified pipe, as it is not so easily broken by a slight settlement or by shocks. It is somewhat expensive and not economical for ordinary use.

In laying pipe culverts, they should be placed on a solid bed, and the earth be well tamped about them. It is desirable to have the bottom of the trench excavated to fit the lower part of the pipe, depressions being formed for the sockets. It is necessary in every case that the pipe be firmly and uniformly supported from below, in order that the culvert may not be broken by settlement, which is especially likely to occur in new work.

The joints in the pipe should be made water-tight, especially where the culvert is likely to flow full or under pressure, as any water escaping through the joints will tend to cause a wash beneath the pipe and undermine the culvert. Joints are commonly filled with clay, but where strength is needed the use of hydraulic cement mortar is preferable. The cost of filling joints is small and adds much to the security of the culvert.

Care should be taken that the culvert have sufficient

slope and be so placed that water may not stand in it, in order to prevent injury from freezing. When this is not feasible, iron pipe should be used. The top of the culvert pipe should be at least 18 inches below the road surface to avoid crushing, and for the larger sizes of pipe (24 to 36 inches), at least two feet.

The ends of pipe culverts should be set in masonry walls to give protection against the washing of the face of the embankment, hold the ends firmly in place, and prevent the entrance of water into the earth on the outside of the pipe.

These walls to give efficient protection must be of substantial construction, going down to a solid foundation below the bed of the stream. They may be built of rubble masonry, and should be laid up in hydraulic cement mortar. Such construction is represented in Fig. 9. The wall must extend far enough on the side

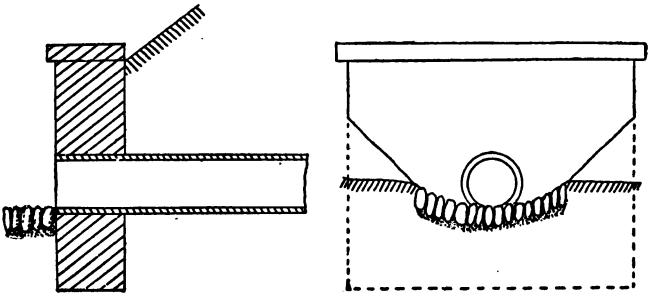


FIG. 9.

to sustain the earth of the embankment from the waterway, or wing walls may be used extending up stream for this purpose. The waterway should be paved above the culvert far enough to prevent scouring at the base of the wall.

For quite small streams the walls may sometimes be omitted if the face of the embankment about the entrance to the pipe and the waterway for some distance above and below be riprapped. Where it is necessary to economize in the cost of construction, this method is preferable to the use of very light end walls.

On streams too large for a single pipe it is often economical to lay two or three pipes side by side, rather than to construct an arch or the open way of a bridge. In laying large pipes it is usually advisable to place a broken-stone or concrete foundation under the pipes throughout their lengths to insure uniform support.

ART. 15. CONCRETE CULVERTS.

Where the waterway required is too large to permit the use of vitrified pipe, concrete culverts are, in most instances, the most economical to use, and in many locations they may be placed more cheaply than the larger sizes of pipe culverts. Concrete, made of good materials, and properly mixed and placed, is a very durable material and will last indefinitely. A well designed concrete culvert should therefore require very little in the way of maintenance.

These culverts are built either with arched or flat tops. For small spans, the rectangular box form is usually the most economical. The arched culvert for small spans is usually built of solid concrete without reinforcement, and is heavier than the box form, unless the culvert be very small. For longer spans the reinforced arch is desirable.

Fig. 10 shows the section of a concrete culvert in which the sides and bottom, as well as the top, are

reinforced with steel rods, for the purpose of taking the tension due to the tendency to bend under the loads which come upon it. Concrete is a good material for resistance to compression, but offers slight resistance to tension; the introduction of steel rods to take the tensions, therefore, make it possible to construct the walls and top of the culvert much lighter than they could otherwise be built.

Structures of this kind must be carefully designed and constructed in order to secure good results. The steel should consist of small rods well bedded in the concrete. They should be placed with the center of the rods about two inches from the inner surface of the concrete. The area of steel required in the top of such a culvert is usually about one per cent of the area of the concrete above it.

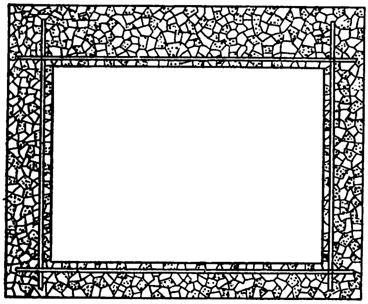


Fig. 10

Concrete culverts, like pipe culverts, must be protected by a covering of earth from the shocks of the traffic. This covering should be 18 inches in thickness, and in no case should be less than 12 inches. The ends of the culvert must be protected by walls, which should extend at least two feet below the bottom of the culvert.

The thickness of the top and sides must depend upon the loads which may come upon the culvert and upon the character of the concrete. They should usually be designed to safely carry a heavy road roller. The concrete should be made of the best grade of Portland

cement mixed with good quality sand and gravel, or broken stone, so as to produce a very dense, homogeneous concrete, the proportions for the top being about 1 part cement, 2 parts sand, 4 parts broken stone; for the sides and bottom, 1 part cement, 2½ parts sand, 5 parts broken stone or 1 part cement, 3 parts sand, 6 parts broken stone. The following tables give approximate dimensions for culverts suitable for country roads under these conditions:

TOP OF CULVERT.					
Span in feet	3	4	5	6	8
Thickness of concrete, — inches	8	9	10	11	13
Size of steel bars, — inches square	⅝	¾	¾	¾	⅞
Distance apart of bars, c. to c. — inches	6	8	7	6	6
BOTTOM OF CULVERT.					
Span in feet	3	4	5	6	8
Thickness of concrete, — inches	5	6	7	8	9
Size of steel bars, — inches square	⅝	½	½	¾	⅞
Distance apart of bars, c. to c. — inches	18	12	10	16	12
SIDES OF CULVERT.					
Height of opening, — feet	2	3	4	5	6
Thickness of concrete, — inches	6	6	7	8	9
Size of steel bars, — inches square	½	½	⅝	⅝	¾
Distance apart of bars, c. to c. — inches	12	10	12	10	12

It may sometimes be desirable to leave out the concrete bottom, and extend the side walls deeper, as with a stone box culvert. Where this is done, the side walls should extend at least 18 inches below the bottom of the culvert, and should widen at the bottom into a footing which will give a firm foundation to the structure.

For small culverts on country roads the side walls may be of plain concrete, with a thickness of about one-third of the height. For the smaller sizes this may in many instances be cheaper than the reinforced sides. For openings not more than 18 inches to 2 feet square a semicircular arched opening, without reinforcement, with a thickness of arch and side wall of about one-third the diameter, may be cheaper than the rectangular form of opening.

In work of this kind, great care must be taken to secure good materials; the broken stone should be of good hard material, not too uniform in size, varying from about $\frac{3}{8}$-inch to $1\frac{1}{4}$ or $1\frac{1}{2}$ inches; sand should preferably be coarse and not uniform in size, it should be clean, hard sand; cement should meet the specifications of the American Society for Testing Materials for Portland cement. The mixing and placing of the concrete must be carefully done so as to secure a thorough and uniform mixture of the ingredients, and a dense, compact mass of concrete in the culvert.

CHAPTER III.

LOCATION OF COUNTRY ROADS.

ART. 16. CONSIDERATIONS GOVERNING LOCATION.

THE determination of a line for a proposed road involves the examination of the country through which the road is to pass with reference to its topographical features, the nature and extent of the traffic that it may develop, and the local interests that may be affected by the position of the road.

The simplest form that this problem can take is that in which two points, as two towns, are to be connected by a road for the purpose of providing for a traffic between them, the nature and amount of which is approximately known. In this case it is only necessary to examine the topography of the intervening country and select the line over which, taking into account the costs of construction and maintenance, the given traffic may be most economically carried.

In most cases in practice, however, the problem does not have this simple character, and in fact location can seldom be determined by considerations of economy alone. The position of the line will be modified by local needs, such as the necessity of providing for the traffic of villages or farms intermediate between the ends of the road, which may often cause deviations from what would be the best line if the interests of the terminal points alone were considered.

Questions of the desirability of various lines for the comfort and convenience of travel, and the pleasure to

be derived from the use of the road, dependent upon æsthetic considerations, may also frequently operate to change the line from what would seem proper from a strictly economic point of view.

In thickly settled communities, as in most parts of the United States, the roads are in the main already located, the necessity for the location of new ones does not often arise, and when it does occur is usually mainly determined by the local needs and requirements of traffic.

The economic considerations involved in the location of roads are of two kinds: those relating to the accommodation of traffic, and those relating to its economic conduct. The first deals with the necessity of the road to the community, the second with the cost of operating it. The first involves the general question of the advisability of any road, and how it can be placed to give the greatest freedom to the movement of travel. The question is as to the value of the road to the general community and its location to secure the greatest good for the least outlay, without taking into account the details of location which may affect the cost of transportation. The value of the road as developing trade in a town or bringing a farm nearer to market would enter into consideration. The accommodation of traffic requires that a road be located with a view to the convenience of its use by the largest portion of the traffic, as well as with a view of developing traffic.

The position of a road that will best accommodate traffic is that in which, other things being equal, the mass of traffic need be moved the least distance in reaching its destination; or, in other words, that for which if each ton of freight be multiplied by the distance through which it must be moved the summation of the resulting products will be a minimum. If there

be differences in the nature of the routes over which the road may be constructed, they may be considered as equivalent to changes in the relative effective lengths of line for purposes of comparison.

The ordinary problem of location deals mainly with considerations of the second class. It consists for the most part in the relocation of portions of old roads, of making such changes in position when improving a road as may tend to reduce the cost of conducting traffic over it and render it more convenient and pleasant for the use of travel, or of determining the details of alignment and grade upon a new road which is approximately fixed in position by the purpose of its construction.

The most economical location is that for which the sum of the annual costs of transportation, the annual costs for maintenance, and the interest on the cost of construction is a minimum.

The cost of conducting transportation is affected by the rate of grade of the road, the amount of rise and fall in it, and the length of the road. The rate of grade is important, because it limits the loads that can be hauled over the road, or determines the number of loads that must be made to transport a given weight of freight, as well as fixes a limit to the speed of travel. The amount of rise and fall affects the expenditure of power required to haul a load over the road. The length of the road has an effect upon the amount of work necessary to haul a load over it, the time required for a trip, and the cost of maintaining the road surface; each of which, other conditions being the same, is directly proportional to the length.

The cost of construction depends upon the accuracy with which the line of the road is fitted to the surface

of the ground, as determining the amount of earthwork and cost of bridges and culverts; upon the character of the ground over which the road is to be built, which affects the cost of executing the work and determines the necessity for and expense of drainage; and upon the cost of land for right of way. All of these items must be considered in any comparison of the cost of constructing on various routes. Special care should be taken in selecting a line to avoid bad ground, such as swamps, upon which construction may be difficult and expensive. The availability near the line of the road of materials needed for surfacing may also become a matter of importance in the cost of construction, and have an influence in determining location.

The relative importance of the various elements affecting the choice of a line depends upon the nature and amount of the traffic to be provided for and upon the character of the road surface to be used. Where the traffic is heavy, the importance of reducing the cost of moving it by lessening grades and distance will be greater than where the traffic is light, and the cost of construction may be correspondingly increased for that purpose. If a smooth surface be employed, upon which traction is light, the value of reducing grades will be greater and the value of reducing distance less than with a surface of poorer tractive qualities.

ART. 17. LENGTH OF ROAD.

Changes in the length of a road affect all portions of the traffic in the same manner, and the expenditure of power and loss or gain in time occasioned by them are in general directly proportional to their amounts.

The value of any considerable saving in length may usually be considered as equal to the same percentage

of the whole cost of conducting the traffic that the saving in distance is of the whole length. If, therefore, a rough estimate may be made of the annual traffic to be expected upon a given line of road and of the cost of carrying the traffic, this cost divided by the length in miles through which the traffic is moved will give the annual interest upon the sum that may reasonably be expended in shortening the road one mile, or upon the value of a saving of a mile in distance; or dividing by the number of feet of distance will give the value of saving one foot.

It is to be noted, however, that the cost of the work of transportation is not necessarily proportional to the amount of work done, and consequently this method would not be strictly accurate even were the data as to traffic and costs readily obtainable. An estimate of this character at best amounts to only a rough guess, but it may often be of use as an aid to the judgment in deciding upon the value of a proposed improvement involving a considerable change of length in a road.

Where the road is so situated and the saving in distance proposed is such that it would enable teams to make an additional trip per day in the hauling of freight, the difference in cost of transportation is quite tangible and readily estimated; but where the traffic is of a more indefinite nature, or the saving proposed insufficient to admit of additional trips, the value of the difference of length depends upon the value to other work of the small portions of time of men and teams which may be saved by the shorter route — a value which exists, but is difficult to estimate.

There is also a value in the saving of distance due to the advantage to the community of bringing the various points closer together, such as bringing two

towns into closer relations or bringing country property nearer to markets. The method of considering the cost as proportional to the work done will therefore probably give a fair idea of the actual economy in any saving in the work of transportation.

The value of reducing distance varies with the character of the road surface. As the cost of transportation is less over a smooth than over a rough surface, on account of the lighter traction, the value of reducing distance is also less on the smooth surface.

The value of saving distance also is greater on a road where the ruling gradients are steep than upon one with light gradients, because of the greater number of loads necessary to move the same traffic.

The cost of maintenance of a road varies with its length, and under similar conditions may be considered, like the cost of transportation, to be directly proportional to the length of road.

The saving in cost of maintenance from decreasing distance must of course be added to that in cost of transportation in order to find the actual value of a change of length.

The value of straightness for a country road is frequently very much overrated. Considerable deviations from the straight line may often be made with but slight increase in length, and there seems to be no good reason for insisting upon absolute straightness. The error is commonly made of sacrificing grade and expense in construction to the idea of straightness without the attainment of any considerable saving in length.

It involves in many cases the injury of the beauty of the road and of the landscape, with no compensating economic advantages.

Art. 18. Rise and Fall.

By the amount of rise and fall is meant the total vertical height through which a load must be lifted in passing in each direction over the road. It is distinct from and independent of the rate of gradient.

The minimum amount of rise and fall is found where the rise is all in one direction and the fall in the other, each being equal to the difference of elevation of the terminal points. Any increase in the rise and fall beyond this amount is represented by the rise encountered in passing from the higher to the lower terminus. This may be considered as avoidable rise and fall. If the cost of developing the work necessary to overcome rise and fall be the same as that of developing an equal amount of work to overcome distance, the rise and fall may be evaluated in terms of distance, and any change in rise and fall may be considered as though it were a difference in distance and treated as in Art. 17.

The value of rise and fall in terms of distance will depend upon the nature of the road surface, as the work necessary to lift a given load to a given height is a constant, while the work done in hauling a load over a given distance will vary with the resistance offered to traction by the surface. Thus, taking the surface as above, the work of lifting one ton through a rise of 1 foot is 2000 foot-pounds, while with a tractive force of 100 pounds per ton $2000 \div 100 = 20$ feet, the distance a ton may be moved on the level surface in developing 2000 foot-pounds of work. Therefore 1 foot of rise or fall may be considered as equivalent to 20 feet of level distance, and the value of reducing the amount of rise and fall may be found from that for

reducing distance. If the road considered were a first-class macadam road, with resistance of 40 pounds per ton, 1 foot of rise or fall would equal 2000 ÷ 40 = 50 feet of distance.

Where the rate of grade is less than the angle of repose of the wheels upon the road surface (see Art. 2) no additional work is imposed, by avoidable rise and fall, upon teams hauling loads over the road. The amount of work done in lifting the loads up the rise is equal to that done by the grade in diminishing traction in descending the fall, and the total work required is equal to that necessary to haul the loads from one terminus to the other upon a uniform gradient. Upon an undulating road, therefore, where the grades are light, there is no economic advantage in reducing the rise and fall of the road.

When the rate of grade is greater than the angle of repose, the amount of work imposed by avoidable rise and fall is equal to twice that caused by the excess of fall above that at the angle of repose. In this case an additional amount of work must be done in applying a resistance to prevent the too rapid descent of the vehicle in going down the grade. The amount of this work in any case equals the work done in lifting the load to a height equal to the difference between the actual rise of the grade in question and the rise of a grade of the same length and a rate equal to the angle of repose. Thus on an ordinary earth road whose resistance to traction where level is 100 pounds per ton, suppose a grade to occur of 8 feet per 100, 1000 feet in length. For the road surface we have 100 ÷ 2000 = .05, and the angle of repose is a 5 per cent grade. Then 8 per cent − 5 per cent = 3 per cent, or the brake-power necessary to secure uniform motion is

the same as would be necessary to haul the load up a 3 per cent grade, and a grade of 3 in 100 for 1000 feet gives 30 feet. The work to be done in holding back the load for the 1000-ft. grade is therefore the same as would lift the load through a vertical height of 30 feet, or the fall of 8 feet per 100 for 1000 feet has the same effect as 30 feet of rise in the same direction, provided brake-power costs the same as animal power. The work saved to the traffic passing down this grade, by eliminating it as avoidable rise and fall (without changing the ruling gradients), would be twice the above amounts or equal to lifting the loads through 60 feet of rise.

ART. 19. RATE OF GRADE.

The effect of any change in the ruling gradient upon a road depends to a considerable extent upon what portion of the traffic may be carried in full loads. The lighter portions of the traffic are not so seriously affected by heavy gradients as the heavy portions, although there is an advantage in light gradients for any driving. The rate of speed which may be employed will be less upon the portions of the road having heavy grade, and the time occupied in a trip over the road is therefore affected somewhat by the rate of grade.

The desirability of a road for general driving is also much influenced by the gradients employed, as is that value of the road which has for a basis the effect it may exert upon the attractiveness of the locality. These things all have a certain financial value, which of course it is quite impossible to estimate with any degree of accuracy, but which should be considered in determining the allowable maximum gradient in any case in practice.

For heavy traffic, such as the transfer of goods from one town to another or the marketing of country produce, the limitation of load placed upon the traffic by the gradient is a matter of importance, the effect of which is calculable upon the cost of transportation. If in any case the approximate amount of this heavy traffic which is likely to be carried in full loads be determined, the relative costs of its transportation over two lines of differing gradient, other conditions being similar, will be nearly proportional to the number of loads required to move the traffic over each gradient.

In estimating the value of reducing the rate of grade, it may be considered, as in the case of a reduction of length, that its value to the community is represented by the saving in annual costs of transportation, and that the amount that may reasonably be expended in increased cost of construction to effect a reduction of gradient is the sum upon which this annual saving is the interest.

The length of a road and the amount of rise and fall on it determine the amount of work that must be done in hauling a load over the road. The rate of gradient, on the contrary, does not affect the amount of work necessary to move the traffic, but it limits the load that a horse may haul at one trip.

The establishment of a proper rate for the ruling grade of the line is, therefore, usually the most important point in location. In localities where light gradients are easily obtained the problem of location is greatly simplified.

By referring to Art. 3 the comparative loads that a horse may draw up different grades will give some idea of the importance of carefully considering the question of gradient. In nearly all cases in practice

there is a considerable latitude within which gradients may be chosen. It is usually a question of heavier gradients as against greater distance and larger first cost for the road. It may be remarked that it is only under exceptional circumstances that it is either necessary or advisable to use a steeper gradient than 5 per cent on the new location of a country road of any importance. Grades steeper than the ruling gradient may sometimes be introduced over short distances without impairing the efficiency of the road, as horses are usually able to exert for a short time a force much greater than they can continuously exert. If the length of grade be quite short, 200 or 300 feet, a horse can about double his ordinary power in passing it.

Where long steep grades must be used, it is desirable to break them by short stretches of lighter gradients to provide resting-places for horses.

Heavy gradients also have the disadvantage of retarding traffic in the direction of falling grade, and, as suggested in Art. 18, of requiring the expenditure of work to hold the load from too rapid descent.

ART. 20. EXAMINATION OF COUNTRY.

For the purpose of obtaining the requisite data upon which to base the location of a road, it is necessary that a careful examination be made of the topographical features of the country through which the line is to pass. The relative elevations of the termini of the line and of intermediate points should be obtained, and the directions and steepnesses of the various natural slopes determined.

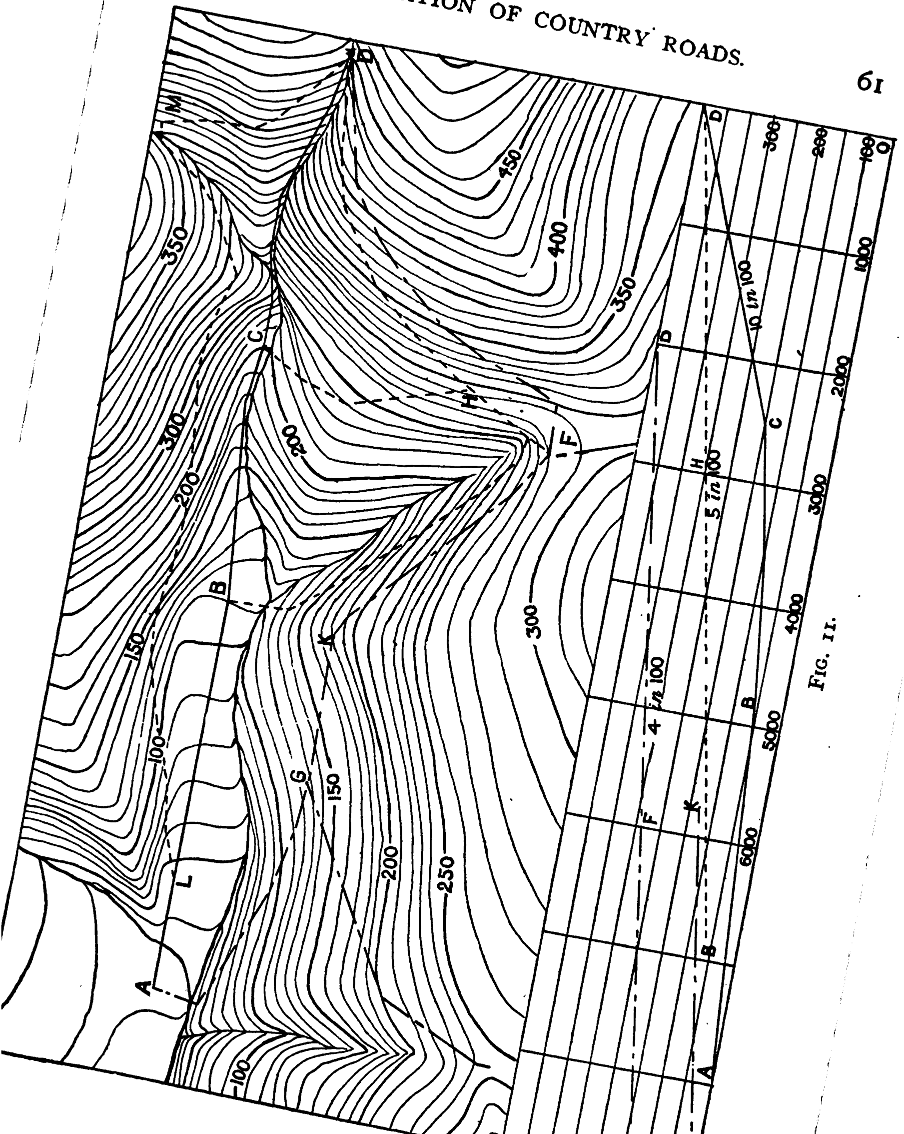
If a line were to be located connecting points at long distances from each other, as sometimes occurs in

railway location, it would be necessary to study the general configuration of the country, noticing the direction of flow of the streams, and the location and elevations of the various passes in the ridges through which it might be possible to carry the line. Usually it would be found that the country is composed of a series of valleys, separated by ridges, branching in a systematic manner from the main watercourse of the region, and that the passes in the ridges occur at the head of side streams, and especially where streams flowing into valleys on opposite sides of the ridge have their sources near each other.

In the location of common roads, however, the problem is ordinarily of a less extended nature, and may consist in joining two points lying in the same valley, or in joining points in adjacent valleys by a line passing over a ridge. In these cases it is only necessary to take into account the slope of the valleys in question, the positions and elevations of available passes, and the side slope of the ridges.

The slope of the bed of a valley, in hilly country, usually forms a concave curve, the rate of slope gradually increasing from the lower to the upper end. In a valley of considerable length this increase in the rate of slope may be very gradual or in short valleys rising to a considerable height it may be more sudden. The profile *ABCD* in Fig. 11 shows the slope of a short valley which decreases in slope from about ten feet per hundred at the upper end to about two feet per hundred at the lower end.

When a map of the country to be traversed is available, showing the positions and elevations of the points controlling the location, the work is very much simplified, the reconnaissance may for the most part be



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1000
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D
2000
C
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5 in 100
3000
4000
4 in 100
B
5000
F
K
6000
B
A
K
A

FIG. 11.

limited to a study of the map, and the routes may be sketched upon the map to be tried in the field. If the map at hand is an accurate contour map on a sufficiently large scale, the entire location may be worked out in detail upon the map, leaving only the work of staking out the line to be done upon the ground.

Maps may be obtained, in most parts of this country, upon which the horizontal positions of points may be readily fixed with sufficient accuracy for the purposes of the preliminary examination. Where such maps are not obtainable, the positions of points must be ascertained and a rough map prepared. For this purpose directions may be measured with a pocket compass, and distances estimated or obtained by the use of an odometer or pedometer, as may be most convenient.

Differences of elevation are easily obtained with a fair degree of accuracy by the use of an aneroid barometer, and slopes may be measured with a hand level.

Where the rough means ordinarily employed in the reconnaissance are not sufficiently accurate to determine the controlling points of the lines to be adopted, a more complete examination of the country may often be made by a rapid topographical survey by means of the transit and stadia method.

Whatever means may be adopted for doing the work, the preliminary examination should determine a map showing the approximate positions of the controlling points through which the road must pass, and enable a rough sketch to be made of the slopes of the country through which the line is to be run.

ART. 21. PLACING THE LINE.

After the preliminary examination of the locality is complete and the positions and elevations of the controlling points of the line are known with reference to each other, the line must be selected and run in upon the ground, or, if the reconnaissance is not conclusive as to the position of the best line, it is advisable to run in two or more lines and make a more detailed comparison between them.

The controlling points of a line are those points at which the position of the road is restricted within narrow limits, and is not subject to change. These may be points where the location is governed by the necessity of providing for traffic, or points where the position of the line is restricted by topographical considerations, such as a summit over which the line is to pass a ridge or a favorable location for a bridge.

Where the line is to be located to a uniform gradient, it should be started from the controlling point at the end of the grade, which is usually the summit. It is then laid off along the slope in such manner as to cause it to have continuously the rate of grade decided upon. Taking *D* (Fig. 11) at the summit of the valley as the controlling point, it is seen that the distance from *C* to *D* is sufficient to give a gradient of 10 in 100 by following directly down the valley, and the line with that gradient may be run in that manner.

The maximum gradient from *A* to *C* is, however, only 5 in 100, and if thought advisable the same maximum gradient may be used between *C* and *D* by running the line *DHC* diagonally down the slope, as shown. This line, having one-half the gradient, will have about twice the length of the line *CD*.

In running this line it is started from the highest point of maximum grade, and points at the surface of the ground are continually selected, in advance of the placing of the line, which are at the proper elevation to permit the grade to pass through them. This may be accomplished by setting off the angle of the gradient upon the vertical circle of the transit, or upon a gradienter, and sighting upon a rod which is moved until the line of sight strikes it at the same height from the ground that the instrument is setting. The points for the line may also be found by running a line of levels ahead of the transit line (a hand level is convenient for this purpose) and pacing distances upon which to reckon the gradient, the distances and elevations being frequently checked upon those of the measured line.

The location of a gradient upon a common road differs from that upon a railroad only in that steeper gradients are used, sharper curves or angles may be employed, and the gradients need not be lessened on ordinary bends or curves. If the line is to make a turn upon the slope as at *H*, the grade should be flattened at the turn, and a curve of as large radius as possible, without too great expense for grading, be introduced.

In a manner similar to the above a line might be run from *D* on the other side of the valley, which using a 5 per cent gradient would give the line *DML*, reaching the bed of the valley at the point *L*. A lighter gradient may be obtained from *A* to *D* by starting from *D* and going down by a continuous gradient of 4 in 100 on the line *DFGA*, and greater or less rates of descent may be adopted and lines corresponding to them located, as may be considered advisable.

The center-line for a final location should be carefully run, and points permanently marked from which it may be relocated when necessary. An accurate line of levels should also be run over the center-line and a profile drawn, upon which the grades may be established and earthwork estimated.

After placing the center-line, topography should be taken carefully upon each side of the line for some distance, and a map drawn showing the topography and giving elevations by means of contours. This will serve to show whether the line is placed to the best advantage, and whether any changes are desirable. This is especially necessary over rough ground or where the line is on maximum gradient, as frequently, and perhaps usually, the first line run will be useful only as a preliminary line, which with its accompanying topography will permit a proper location to be made.

ART. 22. COMPARISON OF ROUTES.

In selecting a line for the construction of a road the principles already mentioned in the early part of this chapter should be had in mind. The line must be well designed to accommodate the traffic. It should have as easy grades, short length, and small rise and fall as is consistent with a reasonable cost of construction, in order to give light costs for transportation and for maintenance.

Suppose in the case shown in Fig. 11 that it is desired to connect the village at the point *A* with the point *D* and with the roads leading through the passes at *F* and *I*. Which line it will be the most advantageous to adopt depends upon the relative importance of the traffic to the various points considered.

The shortest, and probably cheapest, line from *A* to *D* would be obtained by following the valley over the line *ABCD*, which line, as shown by the profile, would give a maximum gradient of 10 in 100 between *C* and *D*. The line *FB* joining the first line at *B* would afford communication with the summit at *F* with a maximum gradient of 5 in 100. If the traffic to the point *D* be small and unimportant, so that additional expense in reducing the gradient from *C* to *D* is unadvisable, these lines might prove a satisfactory location.

If, however, *D* be a point of importance and the traffic from *A* to *D* heavy, it will be necessary to adopt some means to reduce the gradient from *C* to *D*. Leaving out of consideration the point *F* and considering *B* and *C* as points of minor importance, it might be advisable to use the line *ALMD* with a uniform 5 per cent gradient from *D* to *L*, and branches to connect with *C* and *B*. This would give a line but little longer than the valley line, with only one-half the ruling gradient of that line.

If *C* is not important and can be neglected while *B* and *F* must be considered, the line *ABEHD* has a maximum gradient of 5 in 100, and connects *A* with the points *BF* and *D* with a minimum total length of road (being less than the valley line first considered).

When *B* and *C* must both be considered as of importance as well as *F* and *D*, the lines *ABCHE* and *HD* will give a ruling gradient of 5 in 100 to both *F* and *D*, and passing through *B* and *C* with a somewhat longer line than in the last case.

This arrangement would make the length of haul from *A* to *D* and *F* each longer than by the first line considered; but the gradient to *D* would be lighter, and

the total length of road to be constructed and maintained would be less.

In case the points *B* and *C* are both unimportant, and the line through the valley may be neglected, the line *AGFD* provides a ruling gradient of 4 in 100 from *A* to both *F* and *D*, and connects them with each other, with about the same length as the shortest 5 per cent gradient. When the point *I* must be taken into account, this line may be connected with *I* by the line *GI* having a gradient of 4 in 100. This would give the shortest line of uniform gradient to connect *A* with the three points *I*, *F* and *D*, and possibly a desirable line to construct when the line through the point *I* is important, even if the valley road from *A* to *B* is also necessary.

The lines upon the side slopes are usually more expensive to construct than the valley lines, and the differences of first cost of the various lines must of course be considered. The importance of a difference in expense of construction depends upon the traffic to be hauled over the road and the kind of surface to be used. Where a broken-stone or gravel road is to be constructed at considerable expense, the difference of cost due to a change of location is relatively less important as being a less percentage of the whole cost, while the difference of tractive effort due to grade is of more importance, as being a higher percentage of that upon the level, than would be the case with an ordinary earth road.

As is easily seen from the above the choice of a location for a road, while depending upon principles easily stated, is in reality a matter requiring the use of judgment, and is not readily reducible to a financial comparison stated in money values, because the data

concerning the volume of the traffic and the cost of conducting it can be determined only very roughly, and contains many elements of error. For purposes of comparison to aid the judgment, approximate data may often be assumed or determined by a study of the localities affected. In some cases observations may be made of the number of teams of different classes passing certain points within certain times, to give a basis for estimation of the annual volume of traffic. In other cases, the annual hauling traffic, which is usually the most important portion of the traffic in considering location, may be estimated from the known interests of the locality. Thus, if the produce of a certain section of farming country must be hauled over a given road to market, the amount of this produce may be estimated from the acreage, and the relative number of loads upon different grades then determined. The cost per load over the road would then need to be assumed in order to find the annual value of a reduction of grade.

In the same manner, the effect of changes of length and in the amount of rise and fall may be found as indicated in Arts. 17 and 18.

All of these items must be combined to find the relative total costs of transportation for each route. The cost of construction and of maintenance for each line must then be estimated, and that line is the most advantageous which makes the sum of the annual charges and the interest on the first cost a minimum. Where several lines of traffic are to be considered together as in Fig. 11, the cost of conducting all of the traffic by each system of lines that may be employed must be considered, the entire cost being made a minimum for the system to be adopted.

ART. 23. CHANGING EXISTING LOCATIONS.

The problem that arises oftener than any other in country-road location is that of improving short stretches of road, where, owing to defective location, the grades are unnecessarily heavy, the length unnecessarily great, or the ground over which the road may pass such as to make its maintenance in good condition difficult and expensive. The first of these is the most common defect of ordinary country roads, as shortness of distance has very commonly been obtained by the disregard of the desirability of light gradients, which in very many cases are easily obtainable.

The principles to be observed and methods of procedure in making the new location are exactly the same as in an original location, save that in this case a road already exists, and the question of economy is one of determining whether the advantages to be gained in lessened costs of transportation and maintenance is sufficient to warrant the expense of obtaining new right of way and constructing new road.

In Fig. 12 is given an example that is frequently met in practice, where the existing road *abcd* runs over the point of a hill, with heavy gradient, while a line of very much lighter gradient might be located around the base of the hill through the pass at *e*, giving a greater length of road, but much less rise and fall. The line *bed* in the figure has a length about 800 feet greater, a rise and fall 70 feet less, and a maximum gradient one half as steep as the line *bcd*. These relations are shown in the profile in Fig. 12.

If the road in question be a common earth road, 1 foot of rise and fall may be taken as equivalent, in the work required to haul a load over it, to 20 feet of dis-

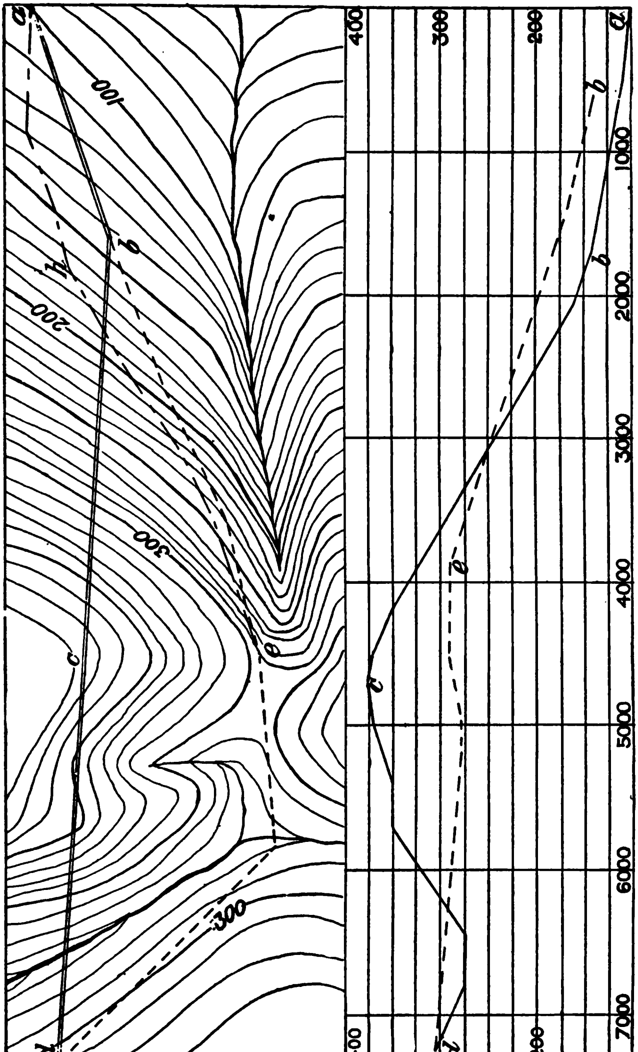
a
b
c
d
e
h
100
200
300
300
400
300
200
1000
2000
3000
4000
5000
6000
7000
400
200

FIG. 12.

tance, and the 70 feet saved by the new location would be equivalent to 1400 feet of distance. Hence, the line *bed* may be considered as having an equivalent length for purposes of traffic $1400 - 800 = 600$ feet shorter than the line *bcd*. In addition to this, loads may be taken over the new line in direction *b* to *d* more than double, and in direction from *d* to *b* triple, in weight those that can be taken by the same power over the old line.

A further improvement of the line may also be possible, if the new line can join the old one at a point lower down than *b*, by running a lighter gradient than 5 in 100 from the point *e*. Thus the line *efa* would give an uniform gradient of 4 per cent, but would require the construction of more new line.

In considering changes of location, it is also necessary to take into account the interests of adjoining owners. Houses and buildings are largely located with reference to the existing position of the roads, and changes in the position of a road may involve injury to such property. The question then becomes largely one of sacrificing the interests of the users of the road, or those of the adjoining owners — a question that should be, but commonly is not, decided by considering what will be of most advantage to the general community.

CHAPTER IV.

IMPROVEMENT AND MAINTENANCE OF COUNTRY ROADS.

Art. 24. Nature of Improvements.

Ordinary country roads may be classified as earth roads, gravel roads, and broken-stone roads. The larger number of common roads throughout this country belong of necessity to the first class. In a few of the more enterprising communities the more important roads are constructed of gravel or broken stone.

The percentage of roads of the better class is, however, very small, and although there has recently been a distinct improvement in this particular, the inability of rural communities to at once raise the funds necessary for the general construction of first-class new roads will cause their increase to be very gradual.

Improvement in country roads may be of several kinds:

(1) Changes in location, by which better alignment or better gradients may be obtained, or by which the natural conditions of surface or drainage may be improved. This has been discussed in Chapter III.

(2) Reconstruction of the road-bed, as in regrading steep slopes to give lighter gradients, or in raising the road-bed across low and wet places to provide for drainage.

(3) The construction of artificial drainage where a road is built over ground which is likely to become soft in wet weather, or where water may reach the road-bed

from underground sources. This has been discussed in Chapter II.

(4) Improvement of the surface, which may consist in re-forming the surface of natural earth, or in the construction of an artificial surface or pavement, the latter of which will be discussed in separate chapters.

The more important lines of travel leading out from the towns will gradually be improved by the construction of broken-stone or other permanent roads, but this constitutes but a small percentage of the total mileage, and the problem in common-road improvement is for the most part that of making the most of the roads that exist, rather than reconstructing them with new material. The materials and funds immediately available must be used to secure as much improvement as possible.

Earth roads, under the most favorable conditions, do not usually attain a high degree of efficiency, and are not economical under any considerable traffic. They are, however, capable of much improvement and need not become, as they frequently do, practically useless during a large portion of the year. This improvement must be gradual and come about through the adoption of more rational methods of maintenance, rather than through immediate reconstruction of the road surfaces.

Art. 25. Grade and Cross Section.

As already explained in Art. 10, the drainage of the surface of a road is accomplished by crowning the surface and giving it a proper longitudinal slope. Underdrains will not drain water from the surface of the road, and unless the crown is at all times maintained and the

surface kept smooth, water is likely to stand upon the surface and soften it.

Grade. The surface of a country road should not be level in the direction of its length, but should have a sufficient longitudinal slope to drain any water from its surface which might otherwise be held by small ruts or depressions. The minimum grade for an earth road should be at least ½ foot in 100 feet, and for a broken-stone road nearly as much. The grade, except in very rough country, should not exceed 4 or 5 feet per 100, and when steeper grades are necessary, they should be made as light as may be feasible. The effect of changing the rate of grade is discussed in Art. 19.

Width. Too great width of roadway upon country roads causes an unnecessary expense in the construction and maintenance of the road, and the width should be only sufficient to provide space for the easy conduct of the traffic. For roads of ordinary traffic, this requires only that there be room for teams moving in opposite directions to freely pass. A width of 20 feet is ample for most country roads, and for roads of lighter traffic 16 feet is often sufficient. Outside of this width, side ditches must be formed for carrying the surface drainage.

In the construction of gravel or broken-stone roads,

FIG. 13.

the paved portion of the road does not usually extend to the full width of the roadway, a shoulder of earth being left on each side, as shown in Fig. 13. The width of broken stone on ordinary country roads may vary

from about 12 feet to 16 feet. A greater width than this need only be employed on important roads which convey large traffic, or on city streets.

While the improved portion of the road should be as small as is consistent with the proper discharge of the duty required of it, the available right of way need not be so restricted, but should be laid out wide enough to permit of the widening of the used portion when necessary, and allow room at the sides for pedestrians, with a grass border and line of trees. When trees are planted along the roadway they should not be placed so as to form a dense shade over any portion of the traveled road, although a moderate shade is not a disadvantage, and care should be used that they are not near enough to a covered drain to permit the roots to grow into the drain and choke it.

Crown. The surface of a road must be crowned sufficiently to cause the water which falls upon it to run at once into the gutters. The height of crown required depends upon the character of the surface and upon the grade of the road. A high crown is objectionable because it concentrates the travel in the middle of the road, which tends to wear hollows longitudinally along the road into which water may settle; but if the crown be too low, small depressions worn into the surface by the traffic may hold water and cause the road to become soft. The slope from the center to the side of an earth road should not be less than one in twenty nor greater than one in ten, corresponding to a height of crown from one-fortieth to one-twentieth of the width of the road. For roads upon which the surface can be kept in smooth condition and on moderate grades, the lower limit may be used, but on the average country road a steeper slope is desirable

and a crown of one-twentieth the width is not too great to secure efficient drainage.

Gravel and macadam roads should be crowned somewhat less than earth roads. On wide macadam streets kept in smooth condition, the side slopes may be as low as one in thirty, or a crown equal to one-sixtieth of the street width. On such work, however, it is more common and probably better to use a crown of one-fiftieth, or even one-fortieth the width; while on ordinary graveled or macadamized country roads the crown should be from one-thirtieth to one-twenty-fourth of the width. When constant attention and careful maintenance can be relied upon to keep the surface in smooth condition a less crown may be used than would be allowable if the road is likely to be subjected to considerable wear between periods when repairs are made.

Form of Section. There is considerable difference of opinion amongst road builders as to the best form to give the surface of a road. Some use a section composed of two planes of equal inclination rounded off in the middle and sloping uniformly to the sides as shown in Fig. 14. Others prefer to use a convex curve,

FIG. 14.

approximately the arc of a circle, or more commonly, a parabolic curve, which is practically identical with the circular arc. The exact form is not a matter of importance on a country road, and either of them, or some intermediate form, may give good results in practice. It is not desirable to insist upon great

accuracy in the form of section provided a proper crown be given and the surface be properly smoothed. Where a smooth pavement is used, however, it is desirable to place it accurately to a uniform section.

Gutters. At the side of the road longitudinal ditches must be provided for the purpose of carrying the water drained from the surface of the road to some point where it may be turned into a natural drainage channel. In many instances these side ditches also carry the drainage from land adjacent to the road. The size and form of the gutters will naturally depend upon the quantity of water to be carried and the slope of the gutters. In some instances the extension of the road surfaces, as shown in Fig. 13, will be sufficient and no special gutters will be required. In deep cuts where the excavation necessary to form side ditches would be expensive, a tile may be placed under each side of the road, as shown in Fig. 16, into which the drainage

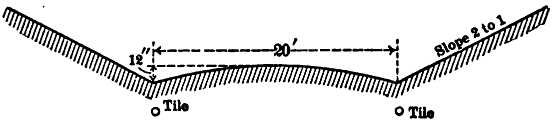

FIG. 16.

from above the cut and from the small gutters may be carried.

Broad, shallow gutters are, in general, to be preferred to deep and narrow ones. The side slopes should not, in any case, be less than 2 horizontal to 1 vertical, and 4 or 5 to 1, on the side next to the roadway, is better. Shallow gutters are easier to form and keep clean, and are not so likely to wash out at times of heavy rainfall. It is not desirable to use deep side

ditches for the purpose of under drainage, and water will not be drawn from the surface of a hollow roadway into such ditches. Fig. 17 shows a common form where it is intended to use the side ditches to prevent any seepage of water from the sides to the road-bed.

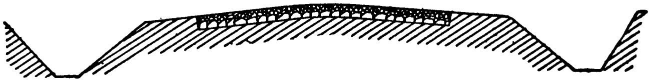

FIG. 17.

This is the standard section given for state aid roads in New York, using a ditch two feet deep with side slopes two to one. This form is also used by the Massachusetts Highway Commission, who recommend ditches 3 feet deep, 1 foot wide at bottom and with slopes 2 to 1. Fig. 18 shows section recommended by the Illinois Highway Commission for use in level

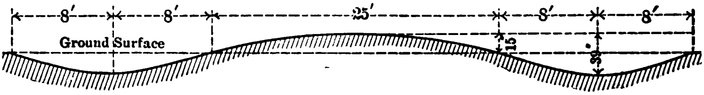

FIG. 18.

country, where the roadway is formed by material excavated from the side ditches.

On the average country road, surface drainage will be amply secured by gutters 18 inches to 2 feet below the crown of the roadway, and side ditches of greater depth are a source of unnecessary expense. Where under drainage is necessary it should be accomplished by tile or other covered drains.

Art. 26. Earthworks.

Improvements to the road-bed of an existing country road may have for their object the reduction of gradient upon steep inclinations by cutting the material from the road-bed and lowering the surface of the road on the upper part of the grade, and filling in correspondingly on the lower part, or they may be intended to provide better drainage by raising the road across low ground.

In the construction of new roads, the formation of the road-bed consists in bringing the surface of the ground to the grade adopted for the road. This grade should be carefully established upon an accurate profile of the line, in such manner as to give as little earthwork as possible, both to render the cost of construction low, and to avoid unnecessarily marring the appearance of the country in vicinity of the road. The most desirable position of the grade line is usually that which makes the amounts of cut and fill about equal to each other, especially where room for borrow-pits, or spoil-banks, would be expensive, and it is desirable to make the embankment for the most part of the material taken from the road excavations. On side-hill work, one side of the road is commonly in cut and the other in fill, and where the side slopes are steep, it is usually better to make the road mostly in cut on account of the difficulty of forming stable embankments on steep ground. In balancing cuts and fills, it is necessary to estimate the quantities for the full width, including side ditches, as the grade should be placed high enough to permit using the material cut from the ditches in the embankment.

Shrinkage. Earth, in embankment, will compact

closer than it is found in its natural state, and allowance for shrinkage must be made in estimating the amount of excavation necessary to form a given embankment. On an average, ordinary soil may be expected to shrink 10 to 12 per cent of its bulk; gravel or sand will shrink a little less than this, 8 or 9 per cent; light surface soils a little more, 14 or 15 per cent. The shrinkage may also be somewhat affected by the method of construction used in forming the embankment, being slightly less for work placed by wagons than for that by scrapers, and still less for wheelbarrow work.

Settlement. In forming an embankment, allowance must sometimes be made for subsequent settlement, by raising the top of the embankment above the required grade. Where scrapers are used, the earth will usually be well compacted in placing, and no allowance is necessary; with dump carts or wagons the compacting is not so thorough, and a small allowance should be made; while when wheelbarrows are used or the earth is thrown into place with shovels, an allowance of 10 or 12 per cent must be added to the height of the embankment, in order to allow for the final shrinkage. Rock occupies more space in embankment than in excavation, and does not need allowance for shrinkage.

Embankments. When embankments are to be constructed, brush and weeds should be removed from the site and at points where the filling is thin, it is desirable to remove all vegetable matter and soft material, to prevent unequal settling and the formation of soft and spongy places in the surface of the road-bed.

In constructing embankments across wet and unstable ground, it is frequently necessary to form an

artificial foundation upon which to place the earth-embankment. This may be accomplished in some cases by excavating a little of the soft material and substituting sand or gravel, or in other cases it may be advisable to employ layers of brushwood or fascines as a support for the enbankment. Sometimes it may be possible to drain the soft material by deep ditches, so as to render it capable of sustaining the road, and in all cases drainage should be provided in so far as possible to make the embankment more secure.

When embankments are to be found on sloping ground, the surface of the ground should be stepped off, in order to hold the earth-filling from sliding upon the natural surface at the line of contact between the two, until it becomes sufficiently settled for the development of cohesion to cause it to become one solid mass.

In many cases where roads are to be constructed along steep slopes, it is found cheaper to use retaining walls to sustain the road upon the lower side and the earth cutting on the upper side than to cut long slopes or form high embankments.

Catch-water drains are necessary on the natural surface above the top of all high slopes in cuttings to prevent the surface water from washing down and destroying the face of the slope.

Where springs are tapped by a cutting, drains must be provided to remove the water without injury to the slope; and where the subsoil may become wet in rainy weather, it may be necessary to provide subsurface drains along the slope to prevent the earth becoming saturated and sliding down into the roadway.

Slopes, both of excavation and embankment, are greatly improved by being sodded or sown with grass. This aids in the maintenance of the slopes, by render-

ing them more capable of resisting the abrading action of such water as falls upon them. It also greatly improves their appearance.

The most important principle involved in the formation of a road-bed, which should be always in mind, is that earth, in order either to sustain a load or to maintain a slope, must be kept dry, or at least prevented from becoming saturated with water, as both the cohesive and frictional resistances of earth are diminished or destroyed when it becomes wet, and it is also then liable to the disturbing action of frost.

Methods of Handling Earth. In the grading of roads or streets, the earth is commonly moved by scrapers, or wagons, after being loosened by plowing. For ordinary work the common railroad plow is used, drawn by two, or in hard material four, horses. In breaking up very hard material, like an old gravel surface, a rooter plow may be needed with four or six horses. Economical handling of the material requires that it be well loosened and the plowing is usually but a small part of the cost.

For moving the loosened earth, drag scrapers may be used for short hauls; they are economical for distances up to about 100 feet. For distances greater than about 80 to 100 feet wheel scrapers will be more economical; for the shorter hauls, the small (number 1) scraper, with a single team to handle each scraper; for longer hauls, above 200 to 300 feet, the larger (number 3) scrapers, with snatch teams to load them. For hauls greater than about 500 to 600 feet, wagons, loaded by men with shovels, will usually be cheaper than scraper work.

In flat country where the grades conform closely to the natural surface, and the road-bed is formed with

earth taken from the side ditches, the use of the elevating grader is usually economical and frequently makes possible the construction of the road at very low cost. This consists of a frame resting upon four wheels, from which is suspended a plow and a wide traveling belt. The plow loosens the earth and throws it upon the inclined belt, which carries it to one side and deposits it near the middle of the road. The ordinary machines are built to deliver the material at about 14 and 17 feet horizontally from the point at which it is excavated. They are usually operated with eight horses.

The ordinary road machine, or scraping grader, is also a convenient tool for this kind of work, and when the amount of material to be moved is small, and the work consists in cutting shallow side ditches and forming a road surface with material taken from them, is usually the most economical tool to employ.

Work done by scrapers will usually be left in rough and lumpy condition. For smoothing the surface, after the earthwork is roughly completed, the scraping grader or some form of road leveler may be used. For this purpose the blade is set so as to cut off the tops of the ridges and lumps, and fill up the hollows, without carrying along any earth.

Work Required in Moving Earth. The work required for moving earth under approximately the same conditions differs widely in practice. It depends upon the character of the material, the methods adopted for the work, the kind of labor available, and, most important of all, the skill with which it is managed.

Loosening. In ordinary compact soil a plow and team with driver and plow holder will loosen 30 to 40

cubic yards per hour. If the material be very hard, an extra team and man will be required for about the same, or a little less, amount of earth; while in hard buckshot, or in breaking up an old road surface, not more than one-half the amount may be loosened.

Drag Scrapers. On short hauls up to about 50 feet, a team with drag scraper may handle from about 4 to 7 cubic yards per hour, and one man will load for 2 or 3 scrapers, depending upon the distance. If the lead be 100 feet, the drag scraper should move from 3 to 5 cubic yards per hour, and one man should load about 4 scrapers.

Wheel Scrapers. Small (number 1) wheel scrapers have a capacity of about $\frac{1}{5}$ cubic yard of compacted earth, and for a haul of 100 feet may be expected to give about the same results as drag scrapers. For longer hauls, about one minute of time of team and driver will be required per trip for each 100 feet of additional distance, or about 5 minutes for each yard of material moved.

The large size (number 3) wheel scraper may be considered as carrying $\frac{1}{3}$ cubic yard at a trip. A snatch team and extra man, or two extra men, will be required to load. These will load a scraper in an average of from one minute to two minutes. Two or three minutes may be allowed for loss of time of scrapers on each trip in loading and unloading, and one minute for each 100 feet of haul. Thus, with a lead of 300 feet, a trip would be made in five or six minutes; 10 or 12 trips per hour, or from $3\frac{1}{3}$ to 4 cubic yards per hour for each scraper.

Wagons. Over ordinary earth roads a team and wagon will carry an average load of 1 cubic yard; on good hard earth roads $1\frac{1}{4}$ yards may be taken. In

loading ordinary soil which has been loosened by plows, men may be expected to average from 1½ to 2 cubic yards per hour. When the work is fairly well organized and as many men are employed in loading as can conveniently work about a wagon (usually about 7 or 8) the loss of time of each team in loading, unloading, etc. may average about 5 to 7 minutes for loads of one cubic yard, while the time occupied in hauling will average about one minute for each 100 feet of lead. When dump wagons are used, about one minute would be saved on each trip.

In estimating the cost of earthwork, about 20 to 25 per cent should be added to the labor cost for contractor's profit, contingencies, etc. The skill with which earthwork is managed has much to do with the cost. Failure to properly organize and systematize the work may easily increase the labor cost 50 per cent. It is not uncommon to find that two pieces of work identical in character, and conducted under the same conditions, differ 25 per cent in cost, because of the difference in the foremen handling the work.

Art. 27. Earth Roads.

The maintenance of an earth road surface in good condition consists in keeping it crowned and smoothed, so that water which falls upon the surface flows away immediately into the gutters without remaining upon the road long enough to do serious harm in softening it. If ruts and depressions are allowed to form in the road surface, they will hold water until it is absorbed into the road or evaporated, thus softening the road so that wheels will cut deeply into it, and gradually destroy its firmness.

The improvement of an earth road surface which is not in good condition must, therefore, be effected mainly by reshaping it into a form with proper crown to shed the water. Its subsequent maintenance requires that it be frequently smoothed to prevent the formation of ruts. It is practically impossible to maintain an ordinary earth road in good condition by the method of annual repairs. Where this method is followed, the road is usually shaped up with a road grader, after it dries sufficiently in the spring, and may present a good surface during the summer and fall. It will, however, be worn hollow by the time bad weather sets in, and will be in condition to hold water and become saturated by heavy rains or melting snow.

Shaping Section. The form of cross section which should be used has already been discussed in Art. 25, and the drainage of the road should be provided for where necessary as described in Chapter II. For cleaning the side ditches and forming the surface of the road, the ordinary road grader, or scraping grader, is used as mentioned in Art. 26. In this work, the blade of the grader is set so as to carry the material from the ditches toward the middle of the road, and repeated trips are made until the proper crown is given to the road surface. In doing this, care should be taken not to leave a ridge of soft material at the middle of the road, but to spread it evenly so that travel may take any part of the road surface, and thus compact it evenly. This may be accomplished by slightly raising the end of the blade of the grader nearest the middle of the road. In using the grader, the amount of material moved and its distribution are controlled by changing the angle at which the blade is set, and the

elevation of its ends. Experience in handling the machine is necessary to its skillful use, and the amount of work required in forming a road is largely dependent upon the skill and experience of the man operating the machine. Good results in such work also require that the teams used be well broken to the work.

Where roads are shaped in this manner in the spring, the work should be done before the surface has become dry and hard, and while the earth is in condition to pack and unite with the surface upon which it is placed. After the ground has become dry and hard, the work is more difficult and expensive, and the road is usually left in bad condition because the material moved, being hard and lumpy, does not pack readily under travel.

Smoothing Surface. The maintenance of an earth road in good condition requires that surface be frequently smoothed so as to prevent the formation of ruts, which may hold water when rain comes. Repairing the road by reforming the surface when it has gotten out of shape may improve it so that it will remain in fair condition so long as weather conditions are favorable, but when rain comes the surface will be softened so that wheels cut in to a small depth, making small indentations. These, if allowed to remain, will hold water at the next rain, causing the road to become soft to a greater depth and deeper ruts to form. If, however, after each rain the road be smoothed out, eliminating the ruts, and moving a little earth toward the middle of the road to replace that lost through wear, the road surface will be hardened and improved at each treatment, and will not retain water when continued rains come upon it.

The smoothing of the road surface should be done

when the road is drying out after a rain; when it is not too muddy, but before it has become hard. The earth is then in condition to pack readily under travel, and will form a smooth hard surface when it becomes dry. If undertaken when the surface is too wet, it may be muddy and sticky to work; after it becomes dry, no good can be accomplished by working it, as it will not pack smooth and hard. When a road is kept shaped up by smoothing it after each rain, the earth composing the road surface becomes puddled, through being worked while wet, until it becomes practically impervious to water and forms a very hard crust on the surface. This effect is observed upon all soils which soften upon absorbing water, and become hard when dry, but is most noticeable upon clay or other heavy soils. The soil which makes the worst and most sticky mud when allowed to become saturated with water makes the hardest and most impervious surface when well maintained.

Methods for Smoothing Surface. Several methods have sometimes been employed for smoothing the surface of an earth road. For the purpose of smoothing out the ruts in the spring, when a muddy road is drying up, a railroad rail 12 to 16 feet in length has sometimes been used, the rail being drawn by teams hitched at the ends so as to cut off the ridges and fill the ruts. A heavy stick of timber faced with steel on one edge has also been used in the same way. These methods may prove quite efficient at times when the roads are in bad condition, causing the surface to dry smoother than would otherwise be the case.

The scraping grader is frequently used for light trimming of the surface, but is not usually an economical tool to use unless heavier work is to be done, on account

of the weight of the machine and the cost of operating it. Several types of light road scrapers, or road levelers, as they are usually called, requiring only a single team and driver, or perhaps also a man to operate the machine, are occasionally used for this purpose. These levelers are sometimes mounted upon two wheels, and the blade made adjustable in position; others are simply cutting blades which slide upon the ground in fixed position. They frequently do good work in smoothing the surface when the soil is in proper condition, although they do not pack the material upon the surface of the road.

Road Drag. The cheapest and most successful method yet devised for maintaining the surface of a road in good condition is by the use of the road drag. This method has been used with great success in the

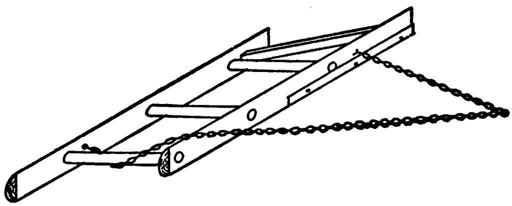

FIG. 19.

states of the Mississippi valley, where the maintenance of earth roads in condition to be used at all seasons had previously been considered an almost hopeless task. Its introduction is largely due to the efforts of Mr. D. Ward King, of Maitland, Mo., who spent most of his time for a number of years in introducing and explaining his method of using the "split log drag." Fig. 19 shows a drag as commonly constructed of split

logs. The following description of the drag and its operation is taken from the report of the Illinois Highway Commission for 1906:

"The log should be from 10 to 12 inches in diameter and about 9 feet long. The holes in the front half of the log should be bored so that a slight slant forward is given to the lower part of the front face of the split log. The holes in the rear log are bored so that its flat face will be perpendicular to the sticks forming the connecting braces which should be tapered at the ends so that they will fit snugly into the holes bored into the logs. The holes should not be less than two inches in diameter. The ends of the cross sticks should be split and wedges driven so as to secure the cross braces in place. The wedges should be driven crosswise of the grain of the log or plank so as not to split it. A diagonal cross brace is placed between the logs at the leading end to stiffen the frame of the drag. The distance from the face of the back log to the face of the front log should be about three feet. The lower front edge or toe of the drag should be protected by a strip of old wagon tire, or other piece of iron, about a quarter of an inch thick and 3 or 4 inches wide and about 4 feet long. This strip of iron should be bolted to the front log and the heads of the bolts countersunk. The strip of iron should not be carried the entire length of the front log.

"Chains should be provided with which to haul the drag, arranged with a short and long hitch as shown in the sketch, so that the drag will travel at an angle of about 45 degrees with the direction of the road. It will be noticed from the sketch that the long hitch of the chain goes over the log around one of the cross pieces rather than through a hole in the front log.

This allows the earth to slide unobstructedly along the front face of the drag."

The drag may also be made of planks, instead of logs; 2 by 12 inch planks are used for this purpose, reinforced on the inner side by 2 inch by 6 inch strips, to provide a greater thickness of wood through which to bore the holes.

"When the road drag is properly used it spreads out the layer of impervious soil over the surface of the road, filling up the ruts and hollows until a smooth surface is secured. As a small amount of material is always to be pushed to the center, a slightly rounded effect will be given to the road, which may be increased or decreased as desired by subsequent dragging. By forcing the mud into the hollows and ruts, it is evident that the water must go out, which it does by running off to the side of the road. The drying out of the road is thus much facilitated and the road is made immediately firmer because the water is squeezed out.

"The effect of traffic over the road tends to press down and thoroughly compact the top of the road and each thin layer of puddled earth which the drag spreads over the surface every time it is used. After the first few draggings it will be noticed that the road is becoming constantly smoother and harder so that the effect of a rain is scarcely noticeable, the water running off the smooth hard surface which absorbs but little of it."

The action of the drag differs from that of an ordinary scraper or leveler in that it packs the material upon the surface, while the leveler merely smooths the road by trimming off the high places and distributing the material into the low places.

Constant attention is necessary to maintain an

earth road in good condition, The dragging should be done as soon after each rain as possible, and at all seasons of the year. If dragging is done before a cold spell, the road will freeze in a smooth condition, and will be in good condition when the frost leaves it.

The amount of work required in dragging roads is comparatively small. While frequent attention is necessary, the work to be done at one time is insignificant. In several instances it has been found that the cost of maintenance by dragging is much less than the expenditure previously incurred for shaping up the road with the grader in the spring.

SAND ROADS.

When a road surface is composed of sand, it will be more firm when the sand is damp and more unstable in dry weather. Such roads require very different treatment from those on clay or loam. No attempt should be made to round up the road, as it is an advantage to retain as much moisture as possible. If clay is available, it is desirable to mix clay with sand in the road surface. If clay is put upon the surface when the materials are damp, the traffic will mix them thoroughly together and the surface will become hard when it dries out, and make a good road surface. It is only necessary to keep the surface smooth while it is drying.

As a general thing, unless a sand road can be resurfaced, it is better to avoid disturbing it, and the less work done upon it the better. If there is but little travel over it, sod and weeds may grow in the sand, and these should not be eradicated.

ART. 28. GRAVEL ROADS.

In the improvement of a country road, where the construction of a good Telford or macadam road cannot be undertaken, a surface of gravel may frequently be used to advantage, giving much better results than could be obtained with the surface of earth. Even a light layer of gravel may frequently prove of very great benefit.

Where the subsoil is of a porous nature and well drained, a layer of three or four inches of gravel, or sometimes even less, well compacted, will constitute a very considerable improvement, especially if, as is usual with these light soils, the nature of the material of the road-bed is particularly unsuitable for the wearing-surface, difficult to compact sufficiently to shed water, and likely to become soft when wet.

Gravel for use on roads should be of hard, tough material, capable of resisting the abrasion of traffic. Natural gravels may differ widely in the character of the materials composing them, and in many instances are harder and more durable than the native stone of the same locality. Nearly any gravel will be an improvement upon an ordinary road surface, but where an important road is being improved the material should be carefully selected. The size of pebbles composing the gravel is important in considering its value for road purposes. As a general thing they should not be more than 1 inch, or at most 1½ inches, in greatest dimension. The size should not be too uniform, but the gravel should contain enough small fragments to fill the interstices between the larger pieces, in order that it may pack well in the road. When the gravel is too fine or too uniform, it will not

bond properly, and will be difficult to compact into a hard surface. The proper gradation of sizes is the most important characteristic of good gravel. The larger pieces are usually the hardest and most durable part of the gravel. They have resisted the grinding action which has reduced the other material to smaller fragments. It is desirable therefore that there be only enough fine material to fill the interstices in that of larger size. When fine material is in considerable excess the gravel should be screened in order to get the best results. In many instances, it is possible to greatly improve the quality of gravel by screening into two or three sizes and then recombining these in proper proportions to produce the most dense material.

Binder. In order to bind well in the road surface, the small spaces between the fragments of gravel must be filled with fine material. Without this the fragments composing the gravel will roll upon each other and not pack well. Natural gravel may contain enough fine material or soft material which will crush under the loads coming upon it to cause it to bind well in the road; or it may be necessary to add some material to the gravel surface to act as a binder. Clay, loam, or stone screenings may be used as a binder. It is desirable to use as little binder as is consistent with the proper bonding of the gravel. When in excess it has a tendency to cause the road to soften in wet weather and to crack in dry weather. This is especially noticeable with clay binder. If gravel contains too much fine material, or when the fine material is unevenly distributed through the gravel, it should be passed over a one half inch screen, and the fine part thus removed be used on the surface as a binder.

When gravel contains considerable large material,

a screen of $1\frac{1}{4}$ to $1\frac{1}{2}$ inches mesh may be used to remove such material from the portion of the gravel to be used in the surface layer of the road. If the road is to be sufficiently thick to be constructed in two layers, the larger pebbles screened from the gravel will be suitable for use in the lower course.

Construction. In the construction of a road with gravel surface the road-bed should first be brought to the proper grade, with a form of cross section the same as that to be given the finished road. The gravel is then placed upon it and rolled to a surface, or left to be compacted by the traffic. It is always advantageous when possible to compact the road by rolling. The road-bed should be well rolled before placing the gravel, and the gravel surface afterward. A smooth hard surface may thus be produced, upon which the wheels of loaded vehicles may roll without producing any visible impression.

In preparing a road-bed for gravel surface, when a light coating of gravel is to be used, the surface of the ground is shaped up with the grader in the ordinary manner, but using a section flatter than the finished road is to have. The gravel is then placed and spread so as to have the proper thickness at the middle and diminish the thin edges at the sides of the road. On a good well drained road-bed, this construction with gravel four or five inches thick at the middle of the road may make a very good country road. Good drainage is, however, essential to success with such a road.

On important roads gravel is often used instead of broken stone, in the manner described in Chapter V. In many localities, gravel exists which is superior in hardness and durability to the local stone available

for road metal. In such instances gravel is often used for surfacing a stone road.

Maintenance. A new gravel road when first opened to travel may require considerable attention to keep it in good condition. The surface should be watched and all ruts or depressions which may form be at once filled up. When new material must be added in repairing a gravel surface, it should be fine and contain more binding material than the gravel used in the first construction of the road.

After a gravel road is thoroughly compacted by the traffic, less attention is required to keep it in surface until it is worn thin enough to require resurfacing.

Art. 29. Oiled Roads.

The use of oil for hardening the surfaces of earth and gravel roads originated in California, where it has rapidly extended into common practice. The use of oil was at first intended only for the purpose of laying the dust, and the surface of the road was sprinkled two or three times during the summer with a light coating of oil. The effect of the oil upon the road was such as to very quickly modify both the purpose and the method of the application, and many roads were soon constructed in which oil was used for the purpose of binding together the material of the road surface, and thus forming a crust over the road which would take the wear of traffic. The results in general were satisfactory, giving, in many instances, smooth firm road surfaces, free from dust during the summer, and without mud in winter.

Methods of Construction. Several methods have been employed in the construction of oiled roads. In the

earlier construction, the oil was applied to the road when hard and smooth, the surface being sprinkled with the oil, which was absorbed into the surface. The following extract from a paper by T. F. White, in Engineering Record for Feb. 22, 1902, explains this method as commonly practiced:

"Oil on roads, besides aiding to make a wearing surface, preserves the road-bed. It follows therefore, that the road-bed should be carefully prepared, well graded and shaped, and the surface smoothed and packed as firmly as the material of which it is composed will permit before the oil is applied. We therefore do our grading during the early part of winter; that the road-bed may have the benefit of the winter rains, and become packed from travel as well as from thorough rolling. We roll after it has become moistened through. Then in the spring, while still moist, we go over it with a blade grader or smoother or both, and dress up the surface, crowning it as desired; and as soon thereafter as the surface is dry and the weather is settled and warm, the oil is applied, as much in quantity as the material will absorb and mix with. This has reference to a road never oiled before.

"It may be desired to put oil on a road that is not in very good shape as to grade and smoothness of surface. It is not recommended to apply oil to such a road, but circumstances may make it seem desirable. In such a road there may be chuck holes full of dust. To oil it we go over the holes first, scraping out the dust, filling them nearly full of oil, and then with hoe and rake, work in the dust, together with sharp sand and fine gravel, which are thrown in from a wagon drawn alongside, until the holes are filled from bottom up with oil, dirt, and gravel, thoroughly mixed together.

When all the holes are filled, we apply a coat of oil to the whole surface of the road. Should the road be very uneven, however, and full of holes, we prefer to haul on gravel, of a kind that will pack, and fill up the holes and uneven places, saturate with water and roll before applying oil. Should the surface of a road be worked up to a considerable depth of dust, if it is of a nature to pack with water and compression, we drench it thoroughly and roll. But if it will not so pack, being of too sandy a nature, we pour on the oil, attempting to saturate all loose material to the firmer stratum below. The only rule we have as to quantity of oil to be applied is to put on sufficient to saturate all of the loose covering of the road, and secure some penetration into the firm road-bed beneath.

"After the oil is put on in any of these instances some appliance for mixing the oil and loose road materials is run over the surface backwards and forwards until a thorough mixing is accomplished. If the road surface is very loose, a common steel lever harrow, with the teeth slanted back, is useful. This may be dragged to and fro longitudinally along the road, and back and forth spirally across the road, until a thorough mixing is secured. On firmer roads and where there is little loose covering, a lighter implement, with numerous dragging fingers suspended from an axle, is better.

"All this has reference mainly to roads that have never been oiled before. When it comes to oiling a road the second, third, and later seasons, the operation is somewhat different. Should the oiled surface be cut through and chuck holes formed (but there will be very few holes if the road has been properly looked after), we go over these in the manner previously

noted for repairing chuck holes, and then apply a dressing of oil to the whole surface, just enough to saturate the loose material and secure a very slight penetration into the old oiled surface. Here I will call attention to a danger we may fall into, that of putting too much oil on the smooth, hard oiled surface we have previously obtained, softening it, and putting it in condition to rut, especially under heavy loads. We may in this way lose a part of the results of the previous year's work. I made this mistake on a road last summer, so can speak from experience. But enough oil should be put on to cover the entire surface as with a thin sheet. Then there will be a surplus of oil, and the road, if left without further attention, would be sticky and very unpleasant to travel over for a considerable time after the application. We therefore follow this application on smooth hard roads that have previously been oiled, with a sprinkling of sand, using fine gravel and sharp sand, such as builders use in their mortars. This takes up the surplus oil and adds to the wearing surface, and renders the road at once comfortable to travel over. The sand soon becomes incorporated with the rest of the road material and packs down smooth and hard. The quantity of sand put on is just sufficient to take up the surplus oil and no more.

"We frequently use this sanding process also when applying oil for the first time to a hard smooth road. We have used it on a macadamized road in which the surface was too tight to absorb the oil, and obtained excellent results. It is useful also where oil is applied to a tight adobe or other clay road. With the oil and sand a wearing surface may be built up on the clay and be made to last, while without the sand the oil

has a tendency to ball up with the clay dust and carry off."

Oil applied to a road surface in this manner is absorbed by the material of the road covering to a small depth, varying, according to the character of the material, from about one half inch to 1¼ inches. This forms a thin coating of oiled material over the surface of the road, which prevents the formation of dust and assists in preventing water from penetrating into the road when rain comes upon it.

In order to secure a greater penetration of oil, in some localities, the soil of the road is loosened by the use of a harrow to a depth of about two inches, before the application of the oil, and is then mixed thoroughly by harrowing again before being compacted by the roller. The method of application varies with the character of the soil, hard soil needing to be loosened and harrowed, or to have a coating of sand added, while sandy soils may be oiled without being disturbed.

In oiling a road for the first time, two applications of oil are usually made, the second application being made at from one week to three months after the first one. In most instances the second application of oil is accompanied by a thin coating of sand or fine gravel, which takes up the surplus oil and forms the wearing surface of the road.

Oil. The oil used for road improvement is commonly crude asphaltic petroleum, with specific gravity 11 to 14 degrees, Baumé, and containing from 30 to 60 per cent of "D" grade asphalt. In the earlier work the oil was always applied hot, at temperatures from 150 to 250 degrees Fahr. In later practice cold oil has frequently been used and each method has its advocates.

The amount of oil required varies with the character of the soil and the method of treatment. As much should be used as the soil will take up. The proper amount can only be judged by experience with the soil to be treated. The quantity of oil used varies from about one-half gallon to 1½ gallons per square yard of road surface for the first application, and one-half to 1 gallon for the second application. The maintenance of the roads usually requires an application of oil each spring, the quantity required decreasing from year to year.

PETROLITHIC PAVEMENT.

The ordinary oiled road consists of a light covering of oiled soil upon the road surface. In some instances oiled surfaces are made 4 to 6 inches deep, by loosening the soil, saturating with oil, and then compacting by rolling to a firm surface. Difficulty has been found in compacting so deep a layer of oiled earth, and this has led to the invention of the petrolithic rolling tamper for this purpose. The rolling tamper is shown in Fig. 20. It consists of a heavy roller with a large number of tampers, or feet, projecting from its surface. These feet pack the material, beginning at the bottom, and thus compress the whole layer to uniform density. An oiled road constructed with this machine is called a petrolithic pavement. The following specifications used in Los Angeles for this class of streets illustrate the method of construction employed in such work:

"After the street has been brought to the required grade and cross-section as above specified, the surface shall be rolled with a roller weighing not less than 250 pounds to the inch width of tire until the surface

is unyielding. Depressions made by the rolling shall be leveled up with good earth and again rolled. Such

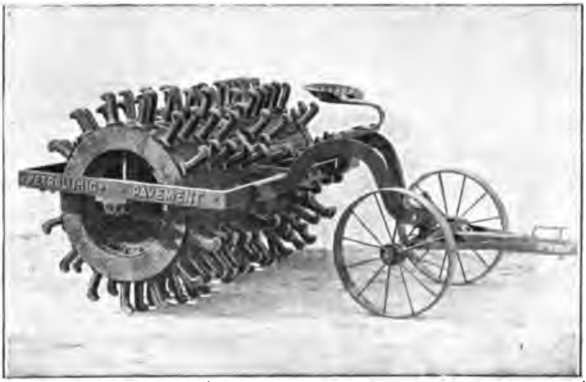

FIG. 20.

portions of the street as cannot be reached by the roller, and all places excavated below grade and refilled, and all pipe trenches and other places that cannot be properly compacted by the roller, shall be tamped solid, and in case of wet weather or soft or muddy ground, making use of the roller unsafe or impracticable, the rolling shall not be undertaken until the ground has become sufficiently dry.

"The street shall then be tested for grade and cross-section, and no further work shall be done upon it until a certificate shall have been issued stating that it is acceptable in these respects. It shall then be plowed to a depth of not less than six inches and thoroughly pulverized by cultivating and harrowing.

OILING.

"Oil shall then be applied as follows:

"The area to be oiled shall extend from curb to curb

where there are no gutters, and where there are gutters then from gutter to gutter, including all intersections of streets and alleys, and to the property line on both sides of said intersections.

"The roadway shall be coated evenly with the oil at the rate of one gallon to the square yard of surface covered. It shall then be thoroughly cultivated to a depth of 4 inches until the oil is well mixed with the soil. A second application of oil, at the rate of one gallon to the square yard of surface covered, shall then be made and the area shall be again cultivated to a depth of 4 inches until the oil and soil are well mixed. The street shall then be plowed 4 inches deep with a plow that thoroughly turns over the furrows.

"A third application of oil, to the extent of one gallon per square yard of surface covered, shall then be made, and the entire surface shall be thoroughly cultivated to a depth of 6 inches, a portion of the cultivating being done along diagonal lines so as to thoroughly mix the surface. The road-bed shall then be tamped with the tamping roller until it is solid to within 3 inches of the finished surface. It shall then be graded with a road grader until it substantially conforms to the official cross-section, and shall then be tamped with the tamping roller until the entire surface is uniformly hard, solid and free from undulations or other irregularities.

"The completed surface of the street must conform substantially to the established grade and cross-section. Should it be low, it shall be broken up to a depth of at least 2 inches, fresh earth and oil supplied and the surface again rolled as before.

"Should an excess of oil remain upon the surface after it has been thoroughly completed, such oily

portion shall be plowed to a depth of at least 6 inches and retamped.

"In the process of cultivating, the surface shall be gone over not less than twice after each of the first two applications of oil, and not less than three times after the third application, and in all cases until the oil and soil are thoroughly mixed.

"The total quantity of oil to be applied on the street shall be not less than three (3) gallons net oil by measure for every square yard of surface covered.

"At all stages of the work sufficient water shall be applied to secure the best results in the tamping, the amount of water to be used to be governed by the character of the soil, the intention being to make the soil just damp enough to pack solid.

"Any portion of the street that cannot be reached by the roller shall be tamped solid by hand, under the direction of the Board of Public Works.

"The contractor will be held responsible for all damage to curbs, gutters, or cross-walks that may be caused by him in the performance of the work.

OIL.

"The oil used shall be crude petroleum and shall conform to the following requirements:

"(a) Specific Gravity: The oil, after being freed from water and sediment, shall be of not less than eleven and five-tenths (11.5) degrees, and not more than fourteen (14) degrees, Baumé, gravity, at sixty (60) degrees F.

"The specific gravity shall be determined by the use of 'The Westphal Specific Gravity Balance,' in conjunction with the accepted scale hereinafter described

for addition and deduction below or above normal temperature.

"(b) Temperature: All oil must be delivered at the point required for sprinkling at a temperature of not less than one hundred (100) degrees nor more than one hundred and ninety (190) degrees F.

"(c) Measurement: In determining the quantity of oil delivered, the correction for expansion by heat shall be as follows: From the measured volume of all oil received at any temperature above 60° F., an amount equivalent to 0.4 of one per cent for every 10° F. shall be subtracted as the correction for expansion by heat. For the purpose of measuring oil a temperature of 60° F. shall be deemed normal temperature.

"(d) Volatility: The oil shall not contain more than eight (8) per cent of matter volatile when said oil is heated slowly to two hundred and twenty (220) degrees F. and maintained at that temperature during fifteen (15) minutes.

"(e) Asphalt: The oil shall contain not less than sixty (60) per cent of asphalt, having at a temperature of seventy-seven (77) degrees F. a penetration of eighty (80) degrees, District of Columbia Standard.

"The percentage of asphalt shall be determined, using oil treated as described in Section (d) in the following manner: A weighed amount of said treated oil shall be heated, in an evaporating oven, to a temperature of four hundred (400) degrees F. until it has reached the proper consistency, when the weight of the residue shall be determined and the per cent calculated.

"(f) Water and Sediment: Deduction will be made for water and sediment in exact proportion to the percentage of such water and sediment found therein, and the oil shall *not* contain over *two* (2) per cent of

such water and sediment as determined by the gasoline test.

"(g) Tank Wagons: All tank wagons used for delivering the oil must first be submitted to the Department of Oil Inspection, which will gauge and stamp into the steel heads of said tanks the capacity in gallons of said tanks, and no figures of capacity will be accepted other than the official rating given by the Department of Oil Inspection.

"(h) All oil to be used shall be tested by the Department of Oil Inspection.

ROLLER.

"The tamping roller to be used in the execution of the work herein specified shall consist of a roller the outer surface of which shall be studded with teeth not less than 7 inches long and having a surface area of not less than 4 square inches each, the roller itself to be of such a weight that the load upon each tooth shall be not less than 300 pounds."

Results of the Use of Oil on Roads. As already stated, good results seem to have been obtained in California with the use of oil both for laying dust on roads and for improving the resistance to wear and to the penetration of water into the road surface. The results obtained depend upon the character of the work and the care used in construction. To secure good results these roads require careful maintenance. The formation of chuck holes due to the action of water upon the road is a principal difficulty, and these require prompt repair. A lightly oiled road surface is worn away by travel and water during the rainy season, and must be annually renewed. On the whole the results are

reported as satisfactory and the use of oil is largely extending.

California has a dry climate, which is very favorable to this kind of construction. The object of the road improvement is rather to get rid of the dust, and cause the surface of the roads to hold together during the dry season, than to guard against the softening of the roads in wet weather. Under these conditions the use of oil constitutes a very desirable method of road improvement; while the occurrence of the asphaltic oil, which may be obtained at low cost, makes possible economical construction.

In considering the advisability of extending such methods to other parts of the country, the differences of climate and of the purpose of road improvement should be taken into account, as well as the character of available materials. Some method of dealing with dust, other than that of sprinkling with water, is annually growing more important, while the breaking up, or raveling, of road surfaces during dry weather is a serious difficulty, particularly where there is considerable automobile travel. The paraffine oils of the Eastern states may act quite differently from the California asphaltic oils, while the greater amount of rainfall and differences in temperature will probably make oiled construction much more difficult to maintain in other parts of the country than in California.

For California the value of these materials has been fully demonstrated, although experience is likely to modify the methods of construction used. For other localities, the value both of materials and methods can be determined only by experiment.

ART. 30. SAND-CLAY ROADS.

In some of the Southern states where other materials for surfacing roads are not available, a mixture of sand and clay in proper proportions has been found a desirable material for this purpose. In some instances the mixing of sand and clay for road work has received considerable attention, and good results have been obtained. The relative amounts of sand and clay to be used depend upon the character of the materials and can only be determined by experiment in each case. Where good materials are available, a fairly hard surface, well adapted to light traffic, may be obtained. It is claimed that these roads are less noisy and less dusty than macadam. They require the same maintenance as an ordinary earth road, but form a harder surface than earth usually found in a natural state. Mr. William L. Spoon, of the United States Office of Public Roads, has made an investigation and report upon this method of construction.

* "The best sand-clay road is one in which the wearing surface is composed of grains of sand in contact in such a way that the voids or angular spaces between the grains are entirely filled with clay, which acts as a binder. Any excess of clay above the amount necessary to fill the voids in the sand is detrimental. If a small section taken from the surface of any well constructed sand-clay road is examined with a magnifying glass, the condition of contact which exists between the grains of sand and the small proportion of clay which is required to fill the voids may be seen. Wherever this proper condition of contact exists for a few inches

* U. S. Department of Agriculture, Office of Public Roads, Bulletin No. 27.

in thickness upon the surface of the road, it will bear comparatively heavy traffic for a long time, even when the subsoil is sand or clay.

"All the experiments which have been made by this Office indicate that the materials should not be mixed in a dry state, but that they should be thoroughly mixed and puddled with water. It makes little difference by what method the stirring or mixing is done, so long as it is thorough and proper proportions of the materials are obtained. If an excess of clay is used in the mixture, the grains of sand which are not in contact are free to move among and upon each other, so that no particle exerts more resistance to pressure than if the entire mass consisted of clay alone. On the other hand, if an insufficient amount of clay is used, the mixture will lack binding power and will soon disintegrate.

"It has been pointed out that thorough stirring and puddling are absolutely essential to successful sand-clay construction. This is most easily brought about immediately after a hard or prolonged rain, the clay having been previously spread and the large lumps broken up as completely as possible. The surface should then be covered with a few inches of sand and plowed and harrowed thoroughly by means of a turning plow and a cutaway or disk harrow. This stage of the work will of course be found somewhat disagreeable, leading, as it does, to the formation of a thick, pasty mud; but it is the only practicable way in which the necessary mixing can be accomplished. Many experiments have been tried with dry mixing of the clay and sand, but all have been more or less unsuccessful. In cases where the plowing and harrowing are considered too expensive, the mixing may be left to traffic. This, however, inevitably leads to a muddy

road surface for a long time, although finally it is possible, by a proper distribution of the sand upon the clay, to bring about a fairly good result, even by this simple method."

"It has already been shown that the best mixture for sand-clay construction is one in which there is just enough clay to fill the void in the sand, thus producing the proper cementing bond in the road surface. No exact rules can be laid down for calculating in advance the best mixture. It must be remembered that the relation of weight and volume will vary widely in different clays, according to the amount of water which they contain. Some clays, especially the more plastic varieties, even after they are as thoroughly dried as they can be by the hottest summer sun, will still hold as much as 20 per cent of water. This water is known to chemists as 'water of combination,' because it seems to be either combined with or held in the structure of the clay particles in such a way that it can only be driven out at a high temperature. It is apparent from this that in handling a clay of this kind, even when it seems quite dry, each ton will contain 400 pounds of water which does not enter into the consideration of volume. The amount of clay necessary to fill the voids in any given sand will therefore be found to vary."

"Practical experience has shown that the tendency is to calculate too little rather than too much sand for given amounts of clay, and almost invariably a second and even a third application of sand is necessary over and above the calculated amount. It often happens that clay will work up to the surface under the action of traffic, in which case an extra top dressing of sand should be added when required."

Upon a clay subsoil "the foundation having been

properly prepared, the surface should be plowed and harrowed to a depth of about 4 inches until it is pulverized as completely as possible. It is then covered with 6 to 8 inches of clean angular sand. The sand should be spread so that the layer is thickest at the center of the road, following in general the same method as was outlined for spreading clay upon a sandy foundation. The first mixing by plow and harrow is now done while the materials are still in a comparatively dry state. It has been found that the clay foundation can be more evenly disintegrated when in that condition. After this first mixing has been finished the road is finally puddled with a harrow after a rain. In case an excess of clay works to the surface and tends to make the mixture sticky, sand is applied until this trouble is overcome.

"Upon the completion of the mixing and puddling, the road should be shaped while it is still soft enough to be properly finished with a scraper and at the same time stiff enough to pack well under the roller or under the action of traffic. In case it is impossible to obtain the proper consistency of the surface material, it is better to shape the road when somewhat too wet than when it is too dry, even if it is necessary to stop traffic upon it for a few days. The road should be opened to traffic as soon as practicable after completion, as this will be found to have a beneficial effect upon it."

Art. 31. Miscellaneous Roads.

Corduroy Roads. In timbered country, where roads must pass over wet and muddy places, corduroy roads are sometimes employed. They are built by laying logs side by side across the roadway. By taking

sufficient care in construction to select the logs and even up the spaces between them with smaller pieces, a reasonably smooth road may be built. Roads of this kind are at best very rough affairs, and require a great deal of work to keep them in fair condition for travel. They are of value only as temporary roads across bad places where the cost of a better road would be too great.

Plank Roads. Many of the old toll roads in some parts of the country were plank roads, and at one time they were quite common. They are now rarely constructed. The road is built of planks 2 to 4 inches thick and 8 or 9 feet long, laid upon two rows of stringers about 5 feet apart. The ends of the planks are not in line but are stepped off to assist wagons in passing from the side upon them. Usually a single line was used and teams turned out upon the earth road at the side in passing; but sometimes a double track was provided for teams in each direction. When in good condition, roads of this kind may be very good for travel, but they very quickly get out of repair and are not economical.

Shell roads. In some localities where oyster shells are plentiful, these are used in constructing roads. They make a road very similar to that built of a soft limestone. The road is constructed in the same manner as with gravel, the shells being readily compacted by the traffic; and binding well in the road. The material is too soft to resist the wear of heavy traffic, and grinds up rapidly under travel. For localities where traffic is not heavy and a harder road covering would be expensive, these roads have often been found satisfactory and economical.

Burnt-Clay Roads. In certain districts in the Southern states, sedimentary clays very commonly

occur, and other road materials are not available. It has been proposed to form a road surface by burning the clay, and experiments have been made by the United States Office of Public Roads which seem to indicate that in many instances this may prove an effective means of road improvement in such localities.

* "After grading the road to an even width between ditches, it is plowed up as deeply as practicable. It will be found necessary to use four horses or mules, as the extremely heavy nature of the clay makes the work of deep plowing difficult. After the plowing has been completed, furrows are dug across the road from ditch to ditch, extending through and beyond the width to be burned. If it is intended to burn 12 feet of roadway, the transverse furrows should be 16 feet long, so as to extend 2 feet on each side beyond the width of the final roadway. Across the ridges formed by these furrows — which should be about 4 feet apart — the first course of cord wood is laid longitudinally so as to form a series of flues in which the firing is started. From 15 to 20 of these flues are fired at one time.

"The best and soundest cord wood is selected for this course and should be laid so that the pieces will touch, thus forming a floor. Another layer of wood is thrown irregularly across this floor, in crib formation, with spaces left between in which the lumps of clay are piled. Care should be taken that the clay placed on this cribbed floor is in lumps coarse enough to allow a draft for easy combustion.

"After the lumps of clay have been heaped upon this floor, another course of wood is laid parallel to the first. The third layer is laid in exactly the same manner

* U. S. Department of Agriculture, Office of Public Roads, Bulletin No. 27.

as the first, and each opening and crack should be filled with brush, chips, bark, small sticks, or any other combustible material. The top layer of clay is placed over all and the finer portions of the material are heaped over the whole structure. A careful arrangement of this cord wood cribbing to separate the clay is important, and the directions should be carefully followed.

"The deep covering of clay which is thrown over all should be taken from the side ditches, and may be in lumps of all sizes, including the very finest material. It is spread as evenly as possible over the top in a layer of not less than 6 to 8 inches. Finally the whole is tamped and rounded off so that the heat will be held within the flues as long as possible. When coal slack is available the two top layers of wood may be omitted and the coal slack thoroughly mixed with the clay.

"It is necessary to get the fires in the flues well under way before the first layer of wood is burned through. The first action of the fire is to drive out the water contained in the clay before the actual burning and clinkering can begin. In burning the gumbo clays a great advantage is gained from the organic and vegetable matter which is contained in the clay, as that in itself aids combustion."

"After the firing is completed not only the portion of the clay which forms the top of the kiln but the ridges between the flues should be burned thoroughly, so as to form a covering of burnt clay 10 to 12 inches in depth, which, when rolled down and compacted, forms a road surface of from 6 to 8 inches in thickness. If properly burned, the material should be entirely changed in character, and when it is wet it should have no tendency to form mud.

"When the material is sufficiently cooled the road-bed should be brought to a high crown before rolling, in order to allow for the compacting of the material. This can best be done with a road grader. After this the rolling should be begun and continued until the road-bed is smooth and hard. The finished crown should have a slope of at least one-half inch to the foot."

Slag Roads. Blast furnace slag is used in some localities as a material for surfacing roads. In some instances also slack from coal mines is used in the same way. Where these materials are available, they may provide a cheap method of improving the surfaces of roads of light traffic. Usually these materials are rapidly reduced to powder under any considerable traffic; in some instances, however, slag may be obtained which is hard and tough and forms a desirable road metal.

ART. 32. WIDTH OF TIRES.

The effect of the width of wheel tires upon the resistance to traction has already been mentioned in Art. 2. For ordinary roads, not in soft condition, tractive resistance is somewhat less for wide than for narrow tires. This difference, while not usually very great, is sufficient to be quite appreciable in the work of hauling heavy loads upon the roads. Narrow tires have a much more destructive effect upon a road surface than wide ones, and from the point of view of road maintenance, wide tires are very desirable. The concentration of a heavy load upon narrow wheel tires affords very little surface of contact between the wheel and road, and causes the wheel to indent the road surface, giving a powerful cutting action. The

same load on a tire of sufficient width would tend to compact the road, acting like a roller, and if these wheels are so placed as not to run in the same track, the difference would be still more marked. There is, however, no advantage in an excessive width of tire. When this exceeds 4 or 5 inches, upon a properly crowned road, the tire will be only partially in contact with the road and the load will be carried on one edge of the tire, which will indent the road surface.

The general introduction of wide tires upon vehicles traveling our highways would greatly simplify the problem of road maintenance, particularly upon earth roads. This fact is generally admitted and appreciated by road builders, but the practical difficulties met in attempting to change the prevailing system of narrow tires has been too great, and the agitation for wide tires has not as yet produced much effect. Many propositions have been made looking toward the regulation of the width of tires by law. This has not met with much success. In some states the laws provide for a rebate upon road taxes to persons using wide tires upon wagon wheels used for highway transportation.

The usual width of tire upon ordinary wagons is 1½ or 1¾ inches. For the best effect upon the highways, these should be increased so as to vary from about 3 to 5 or 6 inches, according to the load for which the wagon is designed.

The wide tire is at a disadvantage on a distinctly bad road, and efforts to secure the adoption of wider tires can hardly meet with much success until very great improvement has taken place in the character of the country roads. Wider tires should naturally follow better roads and assist in maintaining them.

CHAPTER V.

BROKEN-STONE ROADS.

ART. 33. DEFINITION.

BROKEN-STONE roads consist essentially of a mass of angular fragments of rock deposited, usually in layers, upon the road-bed or a foundation prepared for it, and then consolidated to a smooth and uniform surface by means of a roller or by the action of the traffic which passes over it.

There are two commonly recognized systems of constructing broken-stone roads, differing in the nature of the foundation employed, and known respectively by the names of the men who first introduced them into English practice as Telford roads and Macadam roads.

Each of these systems has been greatly modified in use since the time of its founder, and each name is now used to cover a general class of constructions differing very materially within itself as applied in the practice of different engineers. Each of the systems also has its earnest advocates, who contend for its exclusive use, and numerous controversies have been the result, at the conclusion of which each party is "of the same opinion still." The view taken by different road-builders in this matter, it may be remarked, appears to be the result usually of the local necessities of the vicinities in which they work, and of the skill with which the different systems have been applied in work which has come under their observations. In road-building,

as in any other class of engineering works, no rigid rules can be laid down for universal application; each road must be designed for the place it is to occupy and the work it is to do.

In some parts of this country natural gravel is substituted for broken stone in the construction of these roads, the methods of construction being the same as in using broken stone.

ART. 34. MACADAM ROADS.

Macadam roads as commonly constructed consist of two or more layers of broken stone, each layer being rolled to a firm bearing before placing the next. The broken stone is usually placed directly upon the earth road-bed.

In constructing a macadamized roadway, the road-bed is first brought to the proper grade in the usual manner, and rolled to a uniform surface. The surface of the road-bed is either flat or raised at the middle to the same section as is to be given the finished road-surface. The inclined form is usually employed, and seems preferable on account of affording better drainage in case any water finds its way through the surface layer.

On village streets where curb and sidewalks are employed, this section of the road-bed may extend to the curbing (as shown in Fig. 3), but on country roads a bench of earth should be left at the side between the broken stone and the gutter in order to confine the broken stone while it is being compacted, and prevent the spread of the surface materials. The form of the road-bed before placing the stone would then be as shown in Fig. 21, where the completed road is to be of

the form given in Figs. 5 and 17. Where the road-bed is in embankment, it is common to construct the earth embankment to the height of the finished surface, and afterwards excavate the material necessary to admit of placing the surface layers. The embankment should be allowed to settle and become thoroughly compacted before the broken stone is placed upon it, and it is desirable with new embankments that they be used for a short time by the traffic upon the earth surface be-

FIG. 21.

fore finishing the road; where, however, the material is well compacted in construction and can be thoroughly rolled this is not necessary.

In constructing the road-bed its proper drainage must be considered, and where necessary to prevent its becoming wet under the broken stone some means should be adopted to artificially drain it.

Upon the completion of the road-bed, a layer of broken stone, usually from 3 to 5 inches in thickness, is placed upon it and thoroughly rolled. Upon this a second layer is placed and likewise rolled to a uniform surface. Sometimes a third layer is added, or in case of a very thin road it may consist of a single layer, the number of layers depending upon the thickness of the road. When no roller is used, the stone is usually spread on the surface of the road-bed to the full thickness desired for the road, and left to the action of the traffic.

The upper layer constitutes the wearing surface of the road, and upon this it is usually necessary to place

a thin layer of finer material called *binding material*, which may consist of rock chips, sand, small gravel, or sometimes loam, and is washed and rolled into the interstices of the rock, with the object of forming a compact and impervious surface. Binding material is in like manner often added to the lower layers of the road, although this has not been common practice. The object should be to fill the voids in the rock as completely as possible, serving to make the road one solid mass, to bind the rock more firmly together, and to prevent the percolation of water through the surface.

ART. 35. TELFORD FOUNDATIONS.

The distinguishing feature of a telford road is its paved foundation. It consists essentially of a pavement of stone blocks set upon the road-bed and covered with one or more layers of broken stone.

In forming a telford road the road-bed is constructed in the same manner as for macadam, being made either level or crowned. A pavement is then placed upon the road-bed from 5 to 8 inches thick, depending upon the thickness to be given the road material, the general practice being to make the pavement about two thirds of the total thickness of the road. The stones used for the pavement may vary from 2 to 4 inches in thickness and 8 to 12 inches in length; they are set upon their widest edges and with their greatest lengths across the road. The irregularities of the upper part of the pavement are then broken off with a hammer, and all the interstices filled with stone chips and wedged with a light hammer so as to form a completed pavement of about the thickness required.

Upon this pavement the layers of broken stone are placed, and the road-surface completed in the same manner as for a macadam road.

The practice of Telford was to grade the road-bed flat, and then construct his pavement deeper in the middle than at the sides, using for a roadway 16 feet wide stones about 8 inches deep at the middle and 5 inches at the sides. This practice is still followed by some engineers, but it is now more common and usually considered preferable to make the surface of the road-bed parallel to the finished surface and the pavement of uniform thickness. Fig. 22 shows a section of telford road as now commonly constructed.

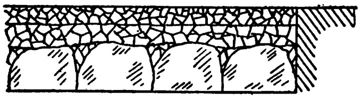

FIG. 22.

The following extract from the specifications of Mr. James Owen, for telford roads in Essex County, New Jersey, may be regarded as representing the best practice in such construction.

"After the road-bed has been formed and rolled, as above specified, and has passed the inspection of the Engineer and Supervisor, a bottom course of stone, of an average depth of —— inches, is to be set by hand as a close, firm pavement, the stones to be placed on their broadest edges lengthwise across the road in such manner as to break joints as much as possible, the breadth of the upper edge not to exceed four (4) inches. The interstices are then to be filled with stone chips, firmly wedged by hand with a hammer, and projecting points broken off. No stone of greater

length than ten (10) inches or width of four (4) inches shall be used, except each alternate stone on outer edge, which shall be double the length of the others and well tied into the bed of the road; all stones with a flat smooth surface must be broken, the whole surface of this pavement to be subject to a thorough settling or ramming with heavy sledge hammers, and thoroughly rolled with a —— ton —— roller. No stone larger than one and one-half ($1\frac{1}{2}$) inches to be left loose on top of telford.'

The proper foundation to be used for a broken-stone road depends upon the nature and condition of the road-bed upon which it is to be constructed and the nature of the traffic to pass over it. If a firm, well-compacted, and thoroughly drained road-bed may be obtained, of material which will not readily soften under the action of moisture, there will usually be no need for a special foundation, but the first layer of the macadam may be placed directly upon the surface of the road-bed. If, however, the road-bed is of a material retentive of moisture, not thoroughly drained, and likely to become soft in wet weather, and the broken stone be laid immediately in contact with it, the stones of the lower layer of macadam may be gradually worked down by the weight of the traffic into the soft earth, and the soil at the same time work up into the voids in the stone, causing a gradual disintegration of the road. It may thus also become retentive of moisture and subject to the disrupting action of frost. In this case some foundation must be provided which is capable of resisting the penetrating action of the soft material of the road-bed and of distributing the load over it.

It is not intended in the above to imply that the

use of a foundation of this character should take the place of proper drainage. The advisability of artificial drainage should always be carefully considered, and where the road is threatened by water which may be removed by the construction of drains they should be used, but frequently thorough drainage is difficult or doubtful, and it is desirable to adopt heavy construction such as the telford foundation gives.

It is commonly claimed by the advocates of the macadam system of construction that on any well-drained and well-compacted road-bed there will be no tendency on the part of the stone to work down or of the soil to work up, and hence that the Telford foundation is an unnecessary expense. The difficulty of procuring a perfectly stable and reliable road-bed in many localities is, however, very generally recognized, and telford pavements are largely used.

The Massachusetts Highway Commission has discontinued the use of telford construction. In their report for 1903 they give the following as their reasons for this course:

"No telford foundations have been laid for two years past. Much of this class of construction has been done by the commission, and every contingency was supposed to have been carefully considered. Notwithstanding the careful attention to details, the results from the use of telford have been far from satisfactory. In a few cases the large stones have come to the surface in a manner which would seem to indicate a movement due to frost action. In other cases, where a fairly soft native stone was used for surfacing, the upper courses were worn away so as to leave the large stones exposed. There are few, if any, cases where equally good results cannot be

obtained by the use of sand, gravel, or small stones in place of telford, and at a less cost."

These difficulties do not seem to have been met by other road builders, and where conditions are such as to make advisable the construction of thick, heavy roads, telford construction is very commonly adopted as the cheapest form for such work.

The Massachusetts Highway Commission has also adopted for difficult construction on wet, heavy soils, a blind center drain, and consider this cheaper than the telford construction. This is described in their report for 1904 as follows:

"On heavy, wet soils a center 'V'-shaped drain has been substituted for the side drains and telfording. In building this type of road the earth is loosened and thrown out toward the sides, so as to give a 'V'-shaped trench, with its greatest depth in the center of the proposed roadway. Narrow trenches are cut through the sides of this center trench, at intervals of 50 or more feet, connecting its lowest part with the gutters on the side, and placed at a depth and slope to thoroughly remove all water. The center and cross ditches are filled with field or wall stone, the depth of this stone varying from 12 to 18 inches at the center, and from 6 to 12 inches on the sides, the thickness being dependent upon the character of the soil in the sub-grade. The tops of these large stones are given a crown to receive the surfacing material."

ART. 36. ROCKS FOR ROAD BUILDING.

Properties Required. The surface material for broken-stone roads must bind together into a solid surface capable of bearing the loads which come upon it and of resisting the wear of the traffic.

A stone to be durable in the surface of a road should be as hard and tough as possible. The qualities of toughness and resistance to abrasion are of more importance than hardness and resistance to crushing. A stone may be hard and brittle and quickly pound to pieces in a road surface, or it may have a high crushing strength and grind away quickly under abrasion, as is the case with some varieties of sandstone. If, however, it be too soft, it may crush under the loads coming upon it, and thus lack in durability.

A stone for a road-surface must also resist well the disintegrating influences of the atmosphere. It should be as little absorptive of moisture as possible in order that it may not be liable to injury from the action of frost. Many limestones are objectionable on this account.

The material of a road-surface should also be uniform in quality; otherwise the wear of the surface will not be even, and depressions will appear where the softer material has been placed.

As the under parts of the road are not subject to the wear of the traffic, and have only the weight of the loads to sustain, it is evidently not important that the foundation or lower layers be of so hard or tough a material as the surface; and hence it is frequently possible, by using an inferior stone for that portion of the work, to greatly reduce the cost of construction.

The binding of the road-surface into a compact mass capable of resisting the wear of traffic depends largely upon the cementing properties of the material. By the cementing power of the stone is meant that property which enables the fine dust to act, when wet, as a cement and bind the fragments of rock composing

the road-surface firmly together. This is perhaps the most important quality of the material, and a high cementing value is always desirable. The tenacity with which the fragments of rock are held together is perhaps more important in the wear of the road than the resistance to wear of the fragments themselves. The powdering of the cementing material in dry weather sometimes causes the loosening of the stones and the raveling of the broken-stone surface. This is more apt to occur where the road metal is hard and resistant to wear than where it grinds up more rapidly.

The character of the material which will give the best results in a road-surface depends upon the local conditions under which the road is to be built and the traffic to which it is to be subjected. Under heavy traffic, hard and tough road metal is necessary to good results. Under lighter traffic, a softer rock may sometimes be better if it is coupled with good binding properties.

* "Experience shows that a rock possessing all three of the properties mentioned in a high degree does not under all conditions make a good road material; on the contrary under certain conditions it may be altogether unsuitable. As an illustration of this, if a country road or city parkway, where only a light traffic prevails, were built of a very hard and tough rock with a high cementing value, neither the best nor, if a softer rock were available, the cheapest results would be obtained. Such a rock would so effectively resist the wear of a light traffic that the amount of fine dust worn off would be carried away by wind and rain faster than it would be supplied by wear. Consequently the binder supplied by wear would be insuffi-

* *Engineering Record*, May 17, 1902.

cient, and if not supplied from some other source the road would soon go to pieces. The first cost of such a rock would in most instances be greater than that of a softer one, and the necessary repairs resulting from its use would also be very expensive."

The selection of material for road metal is commonly determined rather by the cheapness and convenience of location than by its desirability for the purpose. In most instances this is of necessity the case, and the availability of material in vicinity of the work makes possible the construction of the road. It is, however, frequently possible, by judicious selection of materials, to greatly improve the results obtained in such work, and while the selection of a stone for road construction will of course always depend largely upon what is to be obtained in the locality of the work, the importance of a thoroughly good material in the road surface is so great in its effect upon the durability and cost of repairs of the road that it may frequently be found economical, on roads subjected to a considerable traffic, to bring a good material a considerable distance rather than to use an inferior one from the immediate vicinity. It may also be suggested in this connection that in many instances railway transportation over a considerable distance may be small compared with wagon transportation over a short distance, and the importation of good material may add but slightly to the aggregate cost of the work.

Classification. The rocks used for road-building differ widely in their mineral characters. The classification shown in the following table is proposed by Mr. Edwin C. E. Lord.*

* U. S. Department of Agriculture, Office of Public Roads, Bulletin No. 31. 1907.

GENERAL CLASSIFICATION OF ROCKS.

I. Igneous	1. Intrusive (plutonic)	a. Granite. b. Syenite. c. Diorite. d. Gabbro. e. Peridotite.
	2. Extrusive (volcanic)	a. Rhyolite. b. Trachyte. c. Andesite. d. Basalt and diabase.
II. Sedimentary	1. Calcareous	a. Limestone. b. Dolomite.
	2. Siliceous	a. Shale. b. Sandstone. c. Chert (flint).
III. Metamorphic	1. Foliated	a. Gneiss. b. Schist. c. Amphibolite.
	2. Nonfoliated	a. Slate. b. Quartzite. c. Eclogite. d. Marble.

"All rocks of the igneous class are presumed to have solidified from a molten state, either upon reaching the earth's surface or at varying depths below it. The physical conditions, such as heat and pressure, under which the molten rock magma consolidated, as well as its chemical composition and the presence of included vapors, are the chief features influencing the structure. Thus, we find the deep-seated, plutonic rocks coarsely crystalline with mineral constituents well defined, as in case of granite rocks, indicating a single, prolonged period of development, whereas the members of the extrusive, or volcanic, types, solidifying more rapidly at the surface, are either fine grained or frequently glassy and vesicular, or show porphyritic structure. This structure is produced by the development of large crystals in a more or less dense and fine-grained ground mass, and is caused generally by a recurrence of mineral growth during the effusive period of magnetic consoli-

dation. Rocks of this kind, exhibiting a more or less spotted appearance, are commonly described as porphyries, regardless of mineral composition, thus causing great confusion in the nomenclature. A movement in the rock magma while cooling causes frequently a banded arrangement of the minerals, or flow structure."

"Igneous rocks vary in color from the light gray, pink, and brown of the acid granites, syenites, and their volcanic equivalents (rhyolite, andesite, etc.) to the dark steel gray or black of the basic gabbro, peridotite, diabase, and basalt. The darker varieties are commonly called trap. This term is in very general use and is derived from *trappa*, Swedish for stair, because rocks of this kind on cooling frequently break into large tabular masses, rising one above the other like steps, as may be seen in the exposures of diabase on the west shore of the Hudson River from Jersey city to Haverstraw.

"The *sedimentary* rocks as a class represent the consolidated products of former rock disintegration, as in case of sandstone, conglomerate, shale, etc., or they have been formed from an accumulation of organic remains chiefly of a calcareous nature, as is true of limestone and dolomite. These fragmental or clastic materials have been transported by water and deposited mechanically in layers on sea or lake bottoms, producing a very characteristic bedded or stratified structure in many of the resulting rocks."

"*Metamorphic* rocks are such as have been produced by the prolonged action of physical and chemical forces (heat, pressure, moisture, etc.) on both sedimentary and igneous rocks alike. The foliated types (gneiss, schist, etc.) represent an advanced stage of metamorphism on a large scale (regional metamor-

phism), and the peculiar schistose or foliated structure is due to the more or less parallel arrangement of their mineral components. The nonfoliated types (quartzite, marble, slate, etc.) have resulted from the alteration of sedimentary rocks without materially affecting the structure and chemical composition of the original material."

The rocks commonly used for road-building may be classified according to their popular designations as trap, granite, limestone, sandstone, and chert.

Trap. The term "trap" is commonly applied to most of the volcanic igneous rocks used for road-building, including basalt and diabase. While these rocks vary considerably in character, they are usually very compact and tough, and may be classed as the best material for roads of heavy traffic.

* "It is characteristic of all the trappean rocks that they have once been fluid from heat and while in that state have been injected into fissures of the rocks through which they have found their way toward the present surface of the country. Only in rare cases have they actually passed upward to the surface of the earth toward which they moved; their motion was arrested in the lower levels of the rocks to which the surface has been brought down by the agents of atmospheric decay. The result of their consolidation under the conditions of pressure in which they cooled has caused these originally molten materials to be very compact, a state which is favored also by their chemical composition. This causes the materials to be very solid and elastic. They generally resist decay in such a manner that they often project above the surface, while the softer rocks on either side have been worn down."

* Shaler's American Highways, p. 56.

Granite. The granites, including syenite and gneiss, vary widely in character and differ greatly in value as road materials. They may be classed as next in value to trap for wear in the road-surface, but are somewhat deficient in cementing properties.

* "In an examination of the bearing of the petrological characters upon the attrition results in this group three prominent factors stand out. They are: (1) Texture, (2) the kind of mineral, (3) the state of freshness of the minerals. With regard to the first of these it is evident that fineness and evenness of grain is an advantage, and that coarse grain or porphyritic structure is disadvantageous. It is on account of the *granitic texture* that the rocks of this group, taken as a whole, are not higher in the attrition scale.

"The influence of the kind of mineral (2) is not so easy to determine, but, other things being equal, a high proportion of hornblende appears to be favorable to resistance; quartz in a like manner is favorable because of its hardness and lack of cleavage.

"Fresh unaltered original minerals are not absolutely essential to a high capacity to resist abrasion; the two stones that take the best position in the test scale for this group are considerably altered — the feldspars are decomposed, and their substance is a mixture of smaller mineral units; the ferro-magnesian minerals have changed to chlorite and to fibrous uralitic hornblende."

† "In the case of the igneous rocks it will be noted that the plutonic types with granitic granular structure (granite, syenite, diorite, and gabbro) are, as a rule, harder but inferior in toughness to their volcanic

* Lovegrove, Attrition Tests of Road-making Stones, p. 59.

† U. S. Department of Agriculture, Office of Public Roads, Bulletin 31.

equivalents (rhyolite, basalt, and diabase). This is due to the more fully crystalline condition and coarser grain of the plutonic rocks. In the case of the volcanic types a compact crystal intergrowth and fine grain tend to increase the toughness rather than hardness of the material. The deleterious effect of atmospheric decomposition on rock texture is especially noticeable in the case of peridotite, andesite, and altered basalt, where the indifferent results of the physical tests, excepting cementing value, may be directly ascribed to the presence of such soft secondary minerals as kaolin, serpentine, calcite, chlorite, etc. . . . As has already been stated in a previous paragraph, the cementing value is as a rule found more highly developed in the igneous rocks which contain alteration products than in their unaltered varieties. This is especially true in the case of diabase and basalt, rocks very similar in origin and mineral composition. Continuing a step further, we note a marked decrease in toughness, hardness, and resistance to wear in the altered varieties of both these rock types over their fresher representatives. This is in line with what has already been said and indicates that the presence of secondary minerals in appreciable quantities, whether because of their softness or their indefinite semi-crystalline condition, weakens the original mineral bond and tends to destroy the primary texture of the rock, while at the same time furnishing the elements for a high binding quality in the rock powder. Valuable results bearing on the decomposition of rock powders by water have been obtained by Dr. A. S. Cushman in a series of interesting experiments carried on in the chemical laboratory of this Office. Doctor Cushman has shown that hydrolysis takes place in case of many

rock powders the moment they are wet, thus producing secondary products (hydrated silicates) of a colloidal nature which greatly increase the binding power. This points finally to the conclusion that the mineral analysis of igneous rocks, besides providing a convenient means for comparison and classification, serves to a certain extent as a measure of their physical properties."

Limestone. Limestones commonly possess the cementing power in fair degree, although lacking in hardness and resistance to abrasion. The cementing power has probably been commonly overestimated, because of the softness of the rock and the ease with which it usually packs in the road surface. Limestones are the most widely distributed and most generally used materials for road surfaces. They differ very widely in character, some forming an excellent material under moderate traffic and others being so soft as to offer little resistance to wear.

* "In proportion as limestone becomes crystalline, i.e., takes on the character of marble, its value in road-making diminishes, for the reason that the crystalline structure in most cases so far weakens the mass that it is apt readily to pass into the state of powder. As these marbles occur only in districts where better road-making materials are likely to be present, they may not be further mentioned, except to say that their use is commendable for foundation layers, where their fair cementation value makes them tolerably fit for service. So long as the bits are kept from the destructive action of the wheels and feet of the carriages and horses, they lend themselves to the road-master's use. Even where a more resisting top covering of ordinary broken stone

* Shaler's American Highways, p. 61.

cannot be provided, a tolerable road can be made of this material, often very cheaply by using the waste from quarries, by covering the surface with a coating of ferruginous matter, such as is afforded by the leaner iron ores, or by using a top coating of gravel."

* "If we take the pure dolomites alone, it is clear that those behave best in the attrition test which have a fine-grained, even, granular texture with irregular-shaped grains interlocking closely one with another, and with a general absence of porous cavities. A dolomite is by no means always better than a limestone, but the best type of dolomite will be more resistant than the best limestones, being harder.

"Among the limestones, those stand highest that are composed of a mixed assemblage of small organic remains, notably of foraminifera, and possess at the same time a somewhat bituminous composition (this characteristic is often associated with foraminifera in carboniferous limestone). Crinoidal limestones do not stand so high, evidently on account of the ready cleavage of the particles of calcite, which is not only a soft mineral but has an extremely perfect cleavage, hence it wears rapidly and crumbles easily under repeated small blows; but if the crinoid fragments are small and uniform in size, set in a matrix of fine calcareous matter, the stone may compare well with other limestones."

Sandstone. As a class sandstones are deficient in cementing power and do not stand well in the surface of a road. They have commonly been sweepingly condemned and rejected by road-builders. In some instances, however, sandstones have given good results, and some of them possess fairly good cementing

* Lovegrove, Attrition Tests of Road-making Stones, p. 61.

power. The value of a sandstone depends mainly upon the character of the cementing medium; where this is of siliceous character, a high degree of hardness and resistance to wear may result.

* "Considering the next important group of road-making rocks, we notice here also a marked coincidence in mineral composition and physical properties. The soft and nonresistant calcareous rocks (limestones, dolomites, and calcareous sandstones), composed largely of calcite and dolomite, are, as would be expected, inferior in hardness, toughness, and wearing qualities to the more siliceous sandstones and cherts."

Chert. Chert is a very hard material and shows good resistance to wear. It is somewhat low in cementing value, but when carefully used forms a good road material. It is quite variable in character and needs careful selection. Chert is commonly found in a finely divided condition, and can be used, in many instances, without crushing. It occurs throughout many of the Southern states, where it is found widely distributed and is the only available material for such work.

* "The low cementing value of chert obtained by laboratory tests is not in every case in accordance with that developed by this rock under traffic. In discussing the origin of road material it has been stated that chert or flint belongs to that class of sedimentary rocks whose mineral components have been formed largely by chemical precipitation and were originally of a colloidal or amorphous nature. The highly fractured condition of many cherts is probably due in large measure to shrinkage caused by a decrease in

* U. S. Department of Agriculture, Office of Public Roads, Bulletin 31.

volume in passing from an amorphous to a crystalline state. Although no experiments have as yet been made on the solubility of this material, it seems to the writer very probable that the dissolving action of road waters on finely divided chert dust is relatively high and that the high binding power of some of these rocks is caused by hydrated opaline silica resulting from a decomposition of this kind. The fact that in certain localities surface flints are superior to quarry flints for road making is suggestive in this connection."

Mr. Lord, in the bulletin already quoted, gives tables showing the average mineral composition and plates showing structure of the various rocks, and indicates that the probable value of a rock for road-building may be inferred from its mineral composition and structure.

"To explain the bearing of mineral composition and structure on the physical properties of rocks, it has been found necessary to define these properties and describe the various methods for testing road materials. The results of these tests have been used in correlating the physical properties of the various rock families with their mineral components, and the following conclusions have been reached:

"(1) Igneous and metamorphic rocks, owing to a high degree of crystallization and a preponderance of silicate minerals, offer a greater resistance to abrasion than nearly all varieties of sedimentary rocks.

"(2) The coarse-grained intrusive rocks of the igneous class are harder, but break more readily under impact than the finer-grained volcanic varieties of like mineral composition.

"(3) The deleterious effect of atmospheric weathering on the wearing qualities of rocks has been demonstrated.

"(4) The cementing value of rocks is, to a certain degree, measured by the abundance of secondary minerals resulting from rock decay.

"(5) Metamorphic rocks have, as a rule, a low binding power, owing to a regeneration of secondary minerals and to the effects of heat and pressure. The foliated types part readily along planes of schistosity and therefore are not well adapted to road construction.

"(6) The quantitative mineral analysis of rocks serves to a certain extent as a measure of their useful properties for road construction."

Art. 37. Methods of Testing Stone.

Final judgment concerning the value of stone for road purposes, or the best method of using it, can only be formed through experience with the material in use. Tests may, however, be applied which will throw much light upon the probable value of a material, or which may give an idea of the probable relative values of different available materials in a particular case. These tests are of two kinds: 1. Determination of the mineral composition through *petrographic analysis*. 2. Tests of the *physical properties* of road materials.

PETROGRAPHIC ANALYSIS.

The following methods of examination have been used by the Office of Public Roads of the U. S. Agricultural Department, and are described by Mr. Edwin C. E. Lord in Bulletin No. 31, August, 1907.

"Upon receipt of the rock sample, which, according to the specification of this Office, should weigh not

less than 30 pounds and be collected with care to represent as nearly as possible an average of the whole exposure, it is examined in a general way to determine the proper method of analysis.

"Rocks consisting essentially of the carbonates of lime and magnesia (limestones, dolomites, etc.), as well as fine-grained shales and unconsolidated sedimentary deposits, such as clays, sands, gravels, etc., are analyzed chemically when necessary, whereas all other materials are prepared for microscopic examination or determined macroscopically.

"The mineral composition of a rock may, under favorable conditions, be estimated with considerable accuracy by a macroscopic examination, yet for exact quantitative results the aid of a polarizing microscope and transparent thin sections of the rock are essential.

Macroscopic Method. "The macroscopic form of analysis can be applied only to coarse-grained rock, in which the various mineral components are easily detected with the unaided eye. The approximate volumetric relations of these minerals may be determined by preparing a smooth surface of the rock sample and covering it with a transparent celluloid scale divided into 100 equal square areas and estimating the minerals present from the number of areas covered by each mineral. Any properly graduated scale can be used, but a transparent one is preferable."

Microscopic Methods. "Owing to the large amount of material received in this laboratory it has been found necessary to perfect a more rapid method of quantitative analysis than any hitherto described.

"The laboratory is equipped with an exceptionally good petrographic microscope of the latest Fuess model, which, beside the usual attachments, is provided with

a revolving analyzer in the tube to aid in the determination of very low double refracting minerals, and a Schwarzmann scale for the measurement of optical axial angles.

"Another important accessory is a detachable screw-micrometer, movable in the focal plane of the ocular by means of a drum screw, which, with the most powerful objective (one-twelfth-inch oil immersion), records a drum-interval of 0.00004 mm. The measuring apparatus devised by Mr. L. W. Page and used for the mineral determinations consists of an ordinary fixed eyepiece having a square field divided into 100 quadratic areas. With the aid of this cross-line field, each square of which is one one-hundredth of the whole field, the relative proportions, expressed in per cent, of the minerals occupying the field can be readily determined by simply noting the number of squares covered by each mineral in turn. Averages derived from numerous examinations of this kind in various parts of the section indicate the percentage of the different minerals constituting the rock itself."

"Experience has shown that with a large majority of rock samples twenty determinations, using a magnification of 52 diameters, give very satisfactory results. In the case of extremely fine-grained rocks, however, it is best to use a three-quarter-inch objective lens which enlarges 105 diameters when combined with the eyepiece micrometer.

"With rocks having an average grain exceeding 5 mm., or those varying greatly in texture, as in the case of porphyritic and schistose varieties, it is in some instances well to employ a two-inch objective in combination with an ocular prepared in the same manner as that just described, but divided into only

25 square areas and magnifying 30 diameters. In the case of these exceptionally coarse-grained rocks, two or more thin sections of the same sample are examined before reliable results can be obtained."

PHYSICAL TESTS.

The physical properties of stone for road-building are commonly tested by determining the percentage of wear, using the Deval abrasion apparatus, and the cementation properties by the use of the Page cementation test. Tests are also sometimes made of the crushing strength, resistance to impact, and resistance to abrasion by grinding, and, in some instances, the specific gravity and absorption of the rock are determined.

Abrasion Test. This test was first used in France, and is commonly known as the Deval test, bearing the name of its designer. The Deval machine consists of cylinders 20 cm. in diameter and 34 cm. in depth, closed at one end and with a tightly fitting cover for the other. Two or four of these cylinders are mounted upon a horizontal shaft so that the axis of each cylinder is inclined at an angle of 30 degrees with the axis of rotation.

The method of conducting the test in the investigations of the U. S. Office of Public Roads is as follows: * "The sample to be tested is first broken in pieces that will pass in all positions through a 6 centimeter (2.4 inch) ring. The stones are then cleansed, dried in a hot-air bath at 100 degrees C., and cooled in a desiccator. Five kilograms are weighed and placed in one of the cylinders, the cover bolted on, and the machine rotated

*Bureau of Chemistry, Bulletin No. 79.

at the rate of 2000 revolutions per hour for 5 hours. When the 10,000 revolutions of the machine are completed the contents of the cylinder are placed on a sieve of 0.16 centimeter ($\frac{1}{16}$ inch) mesh, and the material which passes through is again sifted through a sieve of 0.025 centimeter (0.01 inch) mesh. Both sieves and the fragments of rock remaining on them are held under running water till all adhering dust is washed off. After the fragments have been dried at 100 degrees C. and cooled in a desiccator they are weighed, and their weight subtracted from the original 5 kilograms (11 pounds). The difference obtained is the weight of the detritus under 0.16 centimeter ($\frac{1}{16}$ inch) worn off in the test."

In the French experiments it was found that the best grades of rock gave about 20 grams of detritus per kilogram of rock tested, and the number 20 was adopted as a standard and the "coefficient of wear" determined from the formula:

$$\text{Coefficient of wear} = 20 \times \frac{20}{W} = \frac{400}{W},$$

in which W is the weight in grams of detritus under 0.16 centimeter ($\frac{1}{16}$ inch) in size obtained per kilogram (2.2 pounds) of stone. The French coefficient is sometimes used in stating results in American tests, but it is more common to ues the "percentage of wear," which is found by stating the weight of detritus under 0.16 centimeter in terms of percentage of the weight of rock tested. In this case,

$$\text{Percentage of wear} = \frac{40}{\text{Coefficient of wear}}.$$

In some of the work of the United States Agricultural Department another coefficient, known as the

United States Agricultural Department coefficient of wear, has been employed. This coefficient is found by subtracting 4000 grams from the weight of the fragments over 3 centimeters (1.2 inches) which remain after the test and dividing the difference by 10. By this method, if 20 per cent of the material is abraded from the original 5000 grams, the coefficient is 0 and the material considered worthless; if no dust is worn off, the coefficient is 100.

The Committee on Standard Tests for Road Materials, of the American Society for Testing Materials, in 1904 recommended the following specification for the abrasion test: "The machine shall consist of one or more hollow iron cylinders, closed at one end and furnished with a tightly fitting iron cover for the other; the cylinders to be 20 centimeters in diameter and 34 centimeters in depth inside. These cylinders are to be mounted on a shaft at an angle of 30 degrees with the axis of rotation of the shaft.

"At least 30 pounds of coarsely broken stone should be available for a test. The rock to be tested should be broken in pieces as nearly uniform as possible, and as nearly 50 pieces as possible shall constitute a test sample. The total weight of rock in a test should be within 10 grams of 5 kilograms. All test pieces should be washed and thoroughly dried before weighing; 10,000 revolutions at the rate of between 30 and 33 to the minute, must constitute a test. Only the percentage of material worn off which will pass through a 0.16 centimeter mesh sieve should be considered in determining the amount of wear. This may be expressed either in the per cent of the 5 kilograms used in the test, or the French coefficient, which is in more general use, may be given."

Cementation Test. This test was developed by Mr. Logan Waller Page while geologist of the Massachusetts Highway Commission. It consists in grinding the stone into dust, wetting and moulding the dust into a small cylinder, which is dried and then tested by subjecting it to the impact of the falling weight. The method of conducting this test as used by the Office of Public Roads of the United States Department of Agriculture is as follows: "One kilogram of the rock to be tested is broken sufficiently small to pass a 6 millimeter but not a 1 millimeter screen. It is then placed in a ball mill and is ground for two hours and a half. This ball mill contains two chilled iron balls which weigh 25 pounds each, and is revolved at the rate of 2000 revolutions per hour. It was found by experiment that grinding rock thus prepared for two hours and a half was sufficient to reduce it to a powder that would pass through a 0.25 millimeter mesh. The dust thus obtained is mixed with water to about the consistency of a stiff dough, and is kept in a closed jar for twenty-four hours. About 25 grams of this dough is placed in a cylindrical metal die 25 millimeters in diameter. A closely fitting plug, supported by guide rods, is inserted over the material, which is then subjected to a pressure of 100 kilograms per square centimeter.

"It is most important that these briquettes should be compressed in a uniform manner, and for this a special machine has been designed. The die is placed on an iron platform supported by a piston rod, which is connected directly with a hydraulic piston below. Water from a tank is admitted to the hydraulic cylinder through a small orifice in the pipe. As the piston rises the platform and die are carried up with it, the

plug of the latter coming in contact with a yoke attached to a properly weighted lever arm. When the lever arm is raised one-eighth of an inch it closes an electric circuit which trips a right angle cock, shutting off the water and opening the exhaust. One minute is required to compress a briquette, and the maximum load is applied only for an instant. By this device practically uniform conditions are obtained.

"The height of the briquette is measured, and if it is not exactly 25 millimeters the required amount of material is added or subtracted to make the next briquette the required height. Five briquettes are made from each test sample, and allowed to dry twelve hours in air and twelve hours in a steam bath. After cooling in a desiccator they are tested by impact in a machine especially designed for the purpose."

The machine commonly used for this purpose is known as the Page-Johnson Impact Machine. It was designed by Mr. L. W. Page and afterward modified by Mr. A. N. Johnson. The blow is delivered by a hammer weighing one kilogram striking upon a flat-end plunger, which is pressed upon the briquette by two light spiral springs. The standard fall of the hammer for a test is 1 centimeter (0.39 inch), and this blow is repeated until the bond of cementation of the material is destroyed. The number of blows required is noted and the average obtained upon five briquettes is given as the cementing value.

In making this test the results may be considerably affected by slight differences in manipulating the material. It is important that the same amount of kneading be used in all tests and that the dough should be allowed to stand at least 24 hours before forming the cylinders.

Grinding Test. The test for abrasion by grinding is sometimes used in France, where it is known as the Dorry test. It has also been used by the Office of Public Roads at Washington. The object of the test is to give a measure of the hardness of the rock. It gives interesting information concerning the material, but is not of special value in testing road material. The test is made as follows: "The test piece in the form of a cylinder about 3 inches in length by 1 inch in diameter is prepared by an annular core drill and placed in the grinding machine in such a manner that the base of the cylinder rests on the upper surface of a circular grinding disk of cast iron, which is rotated in a horizontal plane by a crank movement. The specimen is weighted so as to exert a pressure of 250 grams per square centimeter against the disk, which is fed from a funnel with sand of about 1½ millimeters in diameter. After 1000 revolutions the loss in weight of the sample is determined and the coefficient of wear obtained by deducting one-third of this loss from 20."

Impact Test. This test is intended as a measure of the toughness of the material. It is frequently made, although not of special value as a test for road material. It is made as follows: "The test piece is a cylindrical rock core similar to that used in determining hardness and the test is made with an impact machine constructed on the principle of the pile driver. The blow is delivered by a hammer weighing 2 kilograms, which is raised by a sprocket chain and released automatically by a concentric electro-magnet. The test consists of a 1 centimeter fall of the hammer for the first blow and an increased fall of 1 centimeter for each succeeding blow until the failure of the test piece occurs. The

number of blows required to cause this failure represents the toughness."

The abrasion and cementation tests are frequently employed for the purpose of comparing the properties of various road stones, and afford a means by which a judgment may be formed as to the probable relative values of various materials for road construction. No fixed standard for comparison has been devised, and the relative importance of the various properties depends upon the character of the road to be constructed.

ART. 38. ROAD METAL.

Stone is prepared for use in road work by crushing and screening. In the early days of broken-stone roads, all stone was broken by hand, and the roads were carefully constructed of stone broken to approximately uniform sizes without the addition of a binding material. The development of stone crushing machinery has, however, modified practice in this regard and stone crushed by machinery is now almost exclusively used. It gives satisfaction both as to binding properties and durability, and has the advantage of greatly lessening the cost.

The size to which stone should be broken for road material depends to some extent upon the nature of the material. The harder and tougher it is the smaller the pieces may be without danger of crushing or shattering under the loads and shocks received in the road surface, and the smaller also they will need to be in order to be thoroughly compacted in the road.

There is a difference of opinion among roadbuilders as to the advisability of using stone of uniform size. Some insist quite strenuously upon this point and care-

fully screen their stone with the object of getting it as uniform as possible; while others declare that the variation of size is an advantage, and even that the stone should not be screened after coming from the crusher, except to remove the stone above the limiting size and to get rid of dust and foreign matter.

Uniformity of size probably makes the wear more even, but the presence of smaller fragments facilitates the binding together of the material. If the varying sizes be well distributed through the mass of stone, the variation of size has the advantage of lessening the amount of voids, and makes it possible to compact the stone in the road with a less quantity of binder. Screening out the fine parts and dust eliminates the danger of having portions of the road made up entirely of fine material, and secures a proper distribution of the binder through the mass of stone.

The lower courses of stone in the road may be of any sizes which are most convenient, provided the stones are not too large to become firmly compacted under the roller. When the stones of the surface layer are small in size, it is common to use the larger sizes in the bottom course, thus making it unnecessary to break all to the small dimension.

If the surface of a road is to be constructed of very hard rock the stones for the surface layer may include those from about ½ inch to 1¼ inches (or at most 1½ inches) in diameter with good results. In the work of the Massachusetts Highway Commission: "All broken stone used is separated into three sizes by passing it through a screen with meshes ½ inch, 1½ inches, and 2½ inches in diameter. The largest size is placed at the bottom and is covered with the successive smaller sizes. The different sizes of stone are spread in courses. The sub-grade and

each course of stone are rolled thoroughly, and the top course is watered before rolling."

In constructing roads with limestones, it is often desirable to use larger materials for the surface layer, as these offer better resistance to the wear of traffic. For such roads the surface may be composed of stones from about 1½, or 1¾ inches to 3, or even 3½ inches in diameter; the smaller sizes being used in the bottom course of the road, and the screenings for binder. Stone of this character may also be advantageously used by making both courses of material containing a greater range of sizes, as in the specifications of the Illinois Highway Commission for 1911, which require that:

"Sizes: Two sizes of crushed stone shall be used as follows: (*a*) Broken to a size that will pass over a 1-inch ring, and through a 2½-inch ring, which size will hereinafter be referred to as 2½-inch stone. (*b*) Broken to a size that will pass through a 1-inch ring and graded to a dust, which size will hereinafter be referred to as screenings.

"The first course of stone shall be 2½-inch broken stone spread to compact under rolling to the thickness shown on the plans.

"After the first course of stone has been spread, it shall be harrowed with a stiff-tooth harrow (having a weight of 10 to 12 pounds per tooth) until a uniform size of stone is brought to the surface and all fine material which may have been mixed with the 2½-inch stone has been shaken to the bottom of the layer of stone.

"After the broken stone for the first course has been spread to a uniform thickness and harrowed, and has a proper cross-section, it is to be rolled with a steam roller weighing not less than 10 tons, until it is compacted to form a firm, smooth surface. The rolling must begin at the sides and work towards the center and

the rear wheels of the roller must cover this space thoroughly."

The second course of stone is spread in the same manner as the first, after which the filler is applied, as follows:

"After the second course of stone has been rolled and completed as specified, the screenings are to be spread, but in no case are screenings to be used until the second course has been thoroughly rolled and compacted. The screenings are to be spread dry with shovels from piles along the road, or from dumping boards, but in no case are the screenings to be dumped directly on the second course. The quantity of screenings used is to be such as will just cover the second course of stone.

"After the screenings are spread they are to be sprinkled with water from a properly constructed sprinkling cart and then rolled with a steam roller weighing not less than 10 tons. The amount of water to be used to be determined by the engineer. The rolling is to begin at the sides and to continue until the surface is hard and smooth and shows no perceptible tracks. The rolling and watering shall continue until the water flushes to the surface.

"If after rolling the screenings, the stone appears at the surface, additional screenings shall be used in such places. The rolling is to extend over the whole width of the macadam."

Gravel is frequently used for roads constructed in the same manner as with broken stone, both with and without the telford foundation. The requirements of a good gravel for this purpose are the same as for a good stone. The stones of the gravel should be sharp and angular, and must possess the qualities of hardness and toughness. Water-worn material is therefore objectionable, as it will not compact without the use of

large amounts of soft binding material. In many places a hard flint gravel occurs which is not inferior to the best broken stone. This frequently occurs when the available rock is soft limestone and may be used to advantage as a surface upon a base of the soft rock.

Gravel should be screened to remove the larger stones and the fine material, and then treated in the same manner as broken stone.

Gravel not fit for surface material may often be used to advantage as a base under a surface of hard rock; in many instances, economy would result from the substitution of gravel for broken stone in such work. Slag and cinders may also sometimes be used in the same manner.

In cases where local stone is being used for the lower courses of a road to be surfaced with trap or other more durable rock, or where a flint gravel surface is used upon a soft limestone base, the screenings from the stone used in the lower layer may often advantageously be used in binding the surface, the whole run of the crusher except the screenings through about a one-half inch screen being used in the lower course of the road.

In some instances the binding material is mixed with the surface stone before placing upon the road. The following extract from the specifications of Mr. James Owen for roads in Essex County, New Jersey, shows this practice: "When the two courses are rolled to the satisfaction of the Engineer and Supervisor, a coat of fifty (50) per cent of three-quarters ($\frac{3}{4}$) inch stone and fifty (50) per cent of screenings properly mixed is to be spread of sufficient thickness to make a smooth and uniform surface to the road; then again rolled until the road becomes thoroughly consolidated, hard

and smooth." This specification is remarkable for the large quantity of screenings used, and needs great care in securing a proper mixture of the two materials.

ART. 39. COMPACTING THE ROAD.

The materials may be compacted in a road either by placing them in position and allowing the traffic to pass over them or by rolling with a steam or horse roller.

The first method by itself is seldom practiced when it is possible to avoid it. It is hard upon the traffic, takes a long time to reduce the road to compact condition, and a smooth surface is with difficulty produced. Where heavy horse rollers are employed they are clumsy and inconvenient to handle, and the work of rolling is slow as compared with the steam roller. In many instances, however, good results are obtained with them. They are not so expensive in first cost as steam rollers, and have not the disadvantage of frightening horses.

Horse rollers are usually arranged so that the direction of motion may be reversed without turning the roller itself around, and also so that the weight may be changed by placing additional weight inside the roller or removing it. Horse rollers for this purpose usually bring a pressure of from 125 to 250 pounds per linear inch upon the road and weigh from 3 to 6 tons.

Steam rollers weighing from 8 to 15 tons are most commonly employed for compacting the road materials. They have the advantage of forcing the materials at once into a firm and compact mass and producing a smooth surface for the immediate use of travel. They

admit also of the use of hard materials for binding. These rollers give a pressure under the drivers of from 400 to 650 pounds per linear inch.

The stone forming the body of the road should be placed and partially compacted before the addition of the small material, which may then be worked into the spaces between them.

The office of the binding material is to hold the stones in place and form a bearing for them, as well as to prevent the passage of water between them. It has no duty to perform in sustaining the loads. This is the objection to having the binding material mixed with the stones in advance, as would be the case when unscreened stone is used. A portion of the road stones would be replaced by small material instead of having this material only in such voids as necessarily exist between the stones.

The quantity of binding to be used is that which will be barely sufficient to fill all the voids in the larger material. It has been contended that the lower portion of the road should be porous in order to facilitate the escape of any water that may find its way through the surface, but the tendency of the best modern practice is in the direction of filling all the voids as nearly as possible, thus making the entire road practically one solid body, and it is now commonly agreed that the surface of a properly constructed broken-stone road is very nearly impervious to water.

The voids in loose broken stone comprise about 40 to 50 per cent of the volume. In the stone when compacted in the road the voids are somewhat reduced, probably ranging from 30 to 40 per cent of the volume. The voids may be approximately determined in any

case by filling a measure with the stone, shaken down as closely as possible, and then measuring the quantity of sand that can be added in the same manner.

In constructing a road with the use of a steam-roller, the road-stone is first put on to the required thickness and the roller passed over it to settle the stones into place and reduce the voids as much as possible. The binding material, representing a volume about equal to the voids in the stone, is then added, sprinkled, and rolled until the small material is washed and forced into the interstices, giving a smooth, hard surface. This is repeated for each layer of stone, or in some cases the small material is applied only to the top layer.

A thin coating of the binding material is then spread upon the surface and the road thrown open for travel.

ART. 40. THICKNESS OF ROAD-COVERING.

The thickness necessary for a road-covering depends upon the amount of the traffic it is to bear and upon the nature of the foundation afforded by the road-bed. Under a heavy traffic it is advisable to make the road-covering heavier than might be allowable for lighter traffic, in order to provide for wear and lessen cost of renewals.

When the road-bed is firm, well drained, and not likely to soften at a wet season, it will always afford a firm bearing, upon which the covering may rest. The loads coming upon the road are then simply transmitted through the covering to the road-bed beneath, and there is no tendency on the part of the loads to break through the covering other than by direct crushing of its material. If, however, the road-bed may become soft in wet weather, it will then lose its power to firmly

sustain the covering at all points, and the covering must possess sufficient strength to bridge over places where it is not supported from beneath, or a load coming upon it may break through by bending it downward at such point. The thickness of road-covering, therefore, must be greater where the road-bed is less perfect.

The intensity of freezing that may be expected also has an influence upon the necessary thickness of the road-covering. The effect of frost upon the road will depend in large measure upon the condition of the road-bed, and thus make the thickness depend in still greater measure upon its nature. Freezing will not injure a dry road-bed, but if it be damp and have but a thin covering the road is likely to blow or be thrown up by the action of frost.

For roads on considerable grades the thickness of the road-covering is often reduced below what is used on flat ones, because of the better drainage afforded by the slopes. It is to be remarked, however, that if the slopes are very steep the wear of the surface becomes so great, due to the horses' efforts to obtain foothold and to the washing of surface-waters during rains, that the thickness of the coating should be increased.

Macadam roads are commonly made from 4 to 12 inches thick, and telford roads from 8 to 12 inches, of which 5 to 8 inches may be foundation pavement.

A covering 6 to 8 inches thick is usually sufficient for nearly any case of a country road, unless laid upon bad foundation, or to carry exceptionally heavy traffic. When the road-bed is formed of firm material and well drained, a covering of 4 or 5 inches of broken stone or gravel may give good service under considerable traffic.

A thin road to be effective must have its interstices

well filled with binding material and be thoroughly compacted by rolling. It will then present no voids to be filled by the soil pressing upward from below, and at the same time it will be practically impervious and prevent surface-water from reaching the road-bed, thus keeping the material in good condition to sustain the loads. The 4-inch roads of Bridgeport, Conn., which are often cited as examples of successful work, are constructed in this manner of exceptionally good material. In other cases where thin roads have proved failures the trouble may often be traced to dampness in the subsoil or to lack of thorough construction.

Instances will frequently be met in practice where a road must be constructed over material which is likely to be unstable and cannot be made firm by drainage. In such cases, thick roads must be built. Where the conditions are unfavorable, a road 12 to 16 inches thick may be necessary.

In many cases the problem to decide, in determining the thickness of a covering, is whether to use heavy construction or thorough drainage. It is easier to get good results with thick road-coverings, and they are in general safer to use; but skillful adaptation of less material may often save expense in construction with good results. The peculiar conditions of each case must decide what is best for that case.

On country roads the macadam surface should be given a crown of from one-thirtieth to one-twenty-fourth of the width in order to provide good drainage. In many instances a considerable saving in road material may be effected by making the road thinner at the edges than in the middle. The Massachusetts Highway Commission in some instances reduce the thickness of their 6-inch roads to 2½ or 3½ inches at the edges.

Some engineers grade the road-bed without leaving a bench at the side, and reduce the stone to thin edges. It is doubtful if there is any economy in this practice, as it is wasteful in the use of stone, although it effects a small saving in the cost of grading the road-bed.

Art. 41. Maintenance of Broken-stone Roads.

To maintain a broken-stone road in good condition it is necessary first of all that it be frequently cleaned of mud and dust, and that the gutters and surface drains be kept open to insure the prompt discharge of all water that may come upon the surface of the road.

The best method of making repairs that may become necessary to the road-surface depends upon the character of the material composing the surface and the weight of the traffic passing over it.

If the road metal be of soft material which wears easily, it will require constant supervision and small repairs whenever a rut or depression may appear. Material of this kind binds readily with new material that may be added, and may in this manner frequently be kept in good condition without great difficulty, while if not attended to at once when wear begins to show it will very rapidly increase, to the great detriment of the road. In making repairs by this method, the material is commonly placed a little at a time and compacted by the traffic. The material used for this purpose should be the same as that of the road-surface, and not fine material which would soon reduce to powder under the loads which come upon it. By careful attention to minute repairs in this manner a surface may be kept in good condition until it wears so thin as to require renewal.

In case the road be of harder material that will not so readily combine when a thin coating is added, the repairs may not be so frequent, as the surface will not wear so rapidly and immediate attention is not so important. It is usually more satisfactory in this case to make more extensive repairs at one time, as a larger quantity of material added at once may be more readily compacted to a uniform surface, the repairs taking the form of an additional layer upon the road.

Where the material of the road-surface is very hard and durable, a well-constructed road may wear quite evenly and require very little, if anything, in the way of ordinary small repairs until worn out. It is now usually considered the best practice to leave such a road to itself until it wears very thin, and then renew it by an entirely new layer of broken stone placed in the same manner as in original construction, on top of the worn surface, and without in any way disturbing that surface. If a thin layer only of material is to be added at one time, in order that it may unite firmly with the upper layer of the road it is usually necessary to break the bond of the surface material before placing the new layer, either by picking it up by hand or, if a steam roller is in use, by means of short spikes in its surface. Care should be taken in doing this, however, that only the surface layer be loosened, and that the solidity of the body of the road be not disturbed, as might be the case if the spikes are too long.

Much difficulty has also been experienced in some localities, where the macadam roads connect with earth roads which in wet weather are composed of heavy, sticky mud, on account of the "picking up" of the macadam surface in muddy weather by the wheels of vehicles which are covered with mud. The stones

in the surface are loosened and carried off until the road is destroyed. This has given much difficulty in some of the states of the middle west, where limestone macadam is used. This trouble is reduced by forming the surface of large materials but considerable strength is essential in the binding material to successfully resist destruction from this cause.

The maintenance of macadam roads under trying conditions or under severe traffic has in many instances proven a matter of considerable difficulty and of large expense. Under ordinary circumstances the destruction of a broken stone road is greatest in dry and dusty weather. If the road is subject to considerable travel, wear becomes rapid and a certain amount of the road metal is blown away by the wind, washed away in case of rain, or cleaned from the surface as mud. The binding material wearing into dust and being removed from the road loosens the stones of the road-surface, causing the road to "ravel."

To protect a broken-stone road against excessive wear and prevent raveling in dry weather, some means of laying the dust must be used. Sprinkling the road-surface with water is often used for this purpose and has an important effect in reducing the wear and prolonging the life of the road. If the road be systematically sprinkled, the material ground off by the traffic will pack upon the surface, forming a cushion which serves to protect it from further attrition. In sprinkling, the object should be to keep the surface damp, and not to flood it by applying too large a quantity of water at once.

The recent great increase in the extent of automobile travel upon country roads has introduced a new element into the problem of road construction and maintenance. The destructive effect of these rapidly moving vehicles

is such that, under any considerable traffic of this character, an ordinary macadam road is quickly destroyed, and special methods of construction, or of maintenance, must be employed if satisfactory results are to be obtained. The driving wheels of the automobile produce a backward thrust upon the surface of the road which tends to remove the binder and loosen the stones composing the surface, while the rapid motion of the body of the car causes air currents which draw the dust from the road surface and throw it upward behind the automobile.

The maintenance of country roads against the destructive effect of automobile travel is largely a question of preventing the formation of dust upon the surface of the road. Sprinkling with water may serve in towns, but is expensive and not applicable on country roads. The use of oil in earth-road construction has been discussed in Art. 29, and a number of methods have been proposed for eliminating dust on broken-stone roads; these will be discussed in Art. 42.

Art. 42. Dust Prevention.

The excessive production of dust upon country highways of large traffic presents, to the road engineer, one of the most important problems with which he has to deal. This dust is a source of discomfort to people using the road, or living in its vicinity, a menace to the health of those breathing the dust-laden air, and causes the quick destruction of the surface of the road itself.

The discomforts caused by road dust are evident to all observers. It penetrates into the houses, damaging furnishings and causing increased labor to the housekeeper, injures clothing, and prevents the enjoyment

of lawns and porches. Vegetation in the vicinity of the road is often injured and fruit destroyed.

The effect of dust upon the health of men and animals is not yet fully understood, but enough is known to indicate that dust is an efficient agent for the dissemination of diseases which are communicated by germs. The elimination of dust is considered of special importance in the effort to eradicate tuberculosis.

Road dust consists of very finely divided particles of material abraded from the surface of the road by the traffic, which, when in a dry condition, are easily carried away by the winds or distributed through the air by passing vehicles. The extent to which dust is formed depends therefore upon the resistance of the road metal to abrasion and the tenacity of the binder used to hold the stones together, as well as upon the extent to which the winds and traffic remove the dust from the road surface. If the metal abraded by the traffic would remain upon the surface of the road it would serve to protect the surface from further abrasion, and prolong the life of the road This material, however, is rapidly removed as dust in dry weather, or washed away by rain, leaving the surface exposed to further abrasion.

METHODS OF DUST PREVENTION.

The formation of dust may be lessened by so constructing the road as to cause the surface to offer greater resistance to abrasion and shear of the traffic, or by moistening the surface so as to prevent the particles abraded from flying into the air, and cause them to adhere to each other and to readily pack upon the surface. We therefore distinguish between the treatment applied to ordinary macadam surfaces for the purpose of laying dust, and the

construction of macadam roads with special binders, although the two methods have much the same objects in view.

The construction of broken-stone roads with special binders will be discussed in a separate chapter (see Chap. VI) under the head of Bituminous Macadam. The use of oil upon earth roads for the same purpose has been discussed in Art. 29; here we will consider only the methods used for laying dust upon ordinary macadam surfaces.

Numerous materials have been proposed for use as dust layers and many experiments have been made for the purpose of determining their efficiency in use. Comparatively few of these are of much importance and in consequence of the varying conditions under which the experiments have been made and the different methods of application, it is somewhat difficult to arrive at a definite conclusion as to the relative values of the different materials or the best way of applying them.

Water. As mentioned in Art. 41, the use of water for sprinkling the surfaces of broken-stone roads not only lays the dust, but has a marked effect upon the life of the road by protecting the surface from further abrasion. The use of water for this purpose has, however, the disadvantage of requiring frequent sprinkling on account of the rapid evaporation of the water in dry weather, and is on this account not readily applicable on country roads, where water is not easily available. For the streets of towns, sprinkling is still very commonly employed, but it seems probable that in most instances, upon macadam streets, the amount of labor required is such that a treatment of more permanent character would be cheaper.

Calcium Chloride. The use of calcium chloride ($CaCl_2$) is based upon its hygroscopic and deliquescent

properties. When sprinkled upon the road surface it retains water, or absorbs water from the air, and liquefies, thus keeping the surface moist and preventing the abraded material from drying into dust.

Calcium chloride may be obtained either in a solid granular condition or in a concentrated solution. It is produced as a by-product in the preparation of bicarbonate of soda from common salt by the use of ammonia. When the material must be transported to considerable distances, it is desirable to obtain it in solid form on account of the cost of transportation, but otherwise the solution is convenient as saving the trouble of dissolving the salt.

In applying calcium chloride to a road surface, it is customary to use a solution containing from about 8 to 20 per cent of the salt, and distribute it from an ordinary sprinkling cart. In the first application, the more concentrated solution (perhaps 15 per cent) may be used, and when other applications become necessary a more dilute solution (8 per cent to 10 per cent) is employed. If about 600 gallons of the solution be sprinkled on 1000 feet in length of an 18 feet width of road, from $\frac{1}{5}$ to $\frac{1}{2}$ pound of the calcium chloride is required per square yard of road surface In England, somewhat larger quantities than this have commonly been employed, about $\frac{3}{4}$ pound being used for the first application, with subsequent applications of $\frac{1}{4}$ to $\frac{1}{2}$ pound. On some American roads, applications of less quantities have been found fairly satisfactory, about $\frac{1}{4}$ pound being used for the first, and $\frac{1}{10}$ or $\frac{1}{8}$ pound for subsequent applications.

When the calcium chloride is obtained in solid form it should be dissolved, forming a concentrated solution (40 per cent) in advance of the time when it is to be used, and placed in tanks at points where water may most conven-

iently be obtained, for diluting it, near the road to be treated. The salt is readily soluble in water. If several hours may be allowed for the dissolving to take place, it may be suspended in a wire basket under the surface of the water in the tank until solution is complete, but, if it must be dissolved for immediate use, mechanical agitation must be employed to hasten the process.

In the humid climate of England this method has been employed for laying dust with good results, applications being made at intervals of six weeks or two months during the summer and fall. In the drier climate of the United States, the use of calcium chloride has, in some instances, been found economical as a substitute for sprinkling with water, although it has been found necessary when the air is dry to supply water to the salt by occasional sprinkling, sufficient water not being absorbed from the air during the hot part of the day. This method is not applicable to ordinary country roads in the United States, and can only be used at reasonable cost where water is available along the line of the road for convenient use in sprinkling.

The application of calcium chloride has no permanent effect on the road, and is gradually washed away by the rain and must be renewed several times during the season. It is odorless and clean and, when the atmosphere is sufficiently humid to supply the necessary moisture, is a good dust layer. On residence streets or suburban roads, where water is available, it may be found a satisfactory means of preventing dust, although the cost may be somewhat greater than some of the other methods used for that purpose. In several instances it has been used at a cost of about 2 cents to 4 cents per square yard of road surface per annum, with the calcium chloride about $15 per ton.

* In regard to ascertaining and regulating the strength of the solution, the most convenient method is to determine its specific gravity by means of a hydrometer. Accurate determination have been made of the specific gravity of solutions of known percentage compositions, and, as hydrometers graduated to direct specific gravity readings can be obtained, the method is a very simple one. A hydrometer graduated from 1 to 1.4 is most suitable for ordinary work, and by comparing the readings with the following table, the strength of solution at 15 C. can be immediately ascertained. Also by diluting the salt or concentrated solution with water, any desired strength may be obtained if the dilution is stopped at the specific gravity indicated for that particular strength.

Per cent calcium chloride	5	8	10	15	20	30	40
Specific gravity.......	1.041	1.068	1.086	1.132	1.182	1.286	1.402

Sea-water. Attempts have frequently been made to use sea-water for dust prevention, with the object of reducing the number of sprinklings necessary, and the cost of laying the dust, through taking advantage of the presence of certain hygroscopic and deliquescent salts in the sea-water. The reliance is mainly upon magnesium chloride ($MgCl_2$) which is always found in the sea-water, and which possesses the desired properties to a somewhat less degree than calcium chloride. It has been found that the effect of sprinkling is more lasting than when fresh water is used and the number of sprinklings may be lessened, but the presence in the water of other salts not possessing hygroscopic properties, and which cause disagreeable mud in wet weather, have rendered this treatment, in some instances, rather unsatisfactory. It has been claimed that this salt mud is injurious to

* Hubbard, Dust Preventives and Road Binders, New York, 1910.

horses' feet, and destructive to the iron work of vehicles.

Oil. Bituminous materials have recently come into extensive use as substitutes for water in laying the dust upon macadam roads. These may be used as temporary dust preventives or as permanent road binders. These materials will be discussed in detail in Chapter VI. The asphalts and tar products are not usually employed as temporary dust preventives, but the petroleums are frequently used for the purpose. Many different grades of oil have been tried with varying degrees of success.

Crude Petroleums are very commonly employed. Those having an asphaltic base, like the California oils, give the best results. The heavier parts of these oils have binding properties which exert a lasting effect upon the road, when the more volatile portions have disappeared. The petroleums with paraffine bases, however, like the oils from the Pennsylvania district,possess no binding properties and sometimes produce an objectionable slime which makes them worse than useless. The semi-asphaltic oils from the Texas and Kansas fields have also been fairly successful, but residual oils obtained from these mid-continent petroleums, after the removal of the lighter parts, have been found much more satisfactory, and seem to be the best material available for ordinary sprinkling in the Eastern States, where the cost of transportation would prevent the use of California petroleum.

The oil is easily distributed upon the surface of the road by means of the ordinary sprinkling wagon, $\frac{1}{8}$ to $\frac{1}{4}$ gallon being required per square yard of surface. One or two applications may be needed each season, depending upon the character of traffic upon the road, and the amount and character of oil applied. With oil costing

4 to 5 cents per gallon, the cost of treatment may vary from about $\frac{3}{4}$ to $1\frac{1}{2}$ cents per square yard of road surface. This will usually be considerably cheaper than sprinkling with water or the use of calcium chloride. Oil should not be applied to a surface covered with dust, but the road should be clean and dry when the oil is applied, and dry weather immediately following the application is desirable also, in order to lessen the somewhat objectionable period during which it is being absorbed into the surface.

Oil Emulsions. Various methods have been devised for using oils in the shape of emulsions, with a view to reducing the difficulties and costs of applying the oil to the surface of the road. There are quite a number of processes under various names, some of them patented, and most of them depending upon the use of ammonia or soap solutions as emulsifiers. A machine has also been invented for the purpose of forming emulsions mechanically, without the use of saponifying materials. This is known as the "Emulsifix," and consists of a wagon carrying two tanks, one for the oil and the other for water. These are connected by pipes with a third tank, in which the mixture is formed by rapidly revolving blades, which also force the mixture upon the road surface in a fine spray. The water soon disappears leaving the oil in a finely divided state over the surface to act as a dust layer.

The effect of oil emulsion is temporary and they need to be applied several times during the season. The expense may be somewhat greater than where a single application of oil is made, but the road may be used immediately following the application, without the objectionable conditions which follow the use of a larger quantity of oil. Heavier oils may be used as emulsions

than could be sprinkled cold without the water, and these may act as binders in the road surface after a number of applications, with more lasting effect than the lighter oils.

Chemical emulsions are on the market in concentrated form. These are prepared so as to be readily miscible with water at the site of the work before using. When these contain a good oil of asphaltic base they frequently give good service.

CHAPTER VI.

BITUMINOUS MACADAM ROADS.

ART. 43. TYPES OF BITUMINOUS MACADAM.

THE use of oil upon macadam roads as a means of dust laying has already been considered in Art. 42. Such use has for its object the preservation of the road through preventing the formation of dust. This effect is temporary and needs to be frequently repeated, leaving no permanent binder in the road surface. In the construction of bituminous macadam, however, the purpose is to introduce bitumen into the road surface as a binder, in order to increase resistance to the wear of traffic, by cementing the surface metal firmly together, and impregnating it with bitumen.

The methods employed in constructing bituminous macadam roads are of several different types:

(a) *Surface Treatment,* which consists in applying a coating of bitumen to a finished surface of water-bound macadam. This coating is applied either cold or heated, and is usually covered with a layer of sand or other fine material, and rolled. Two applications are commonly made, the object being to secure an even coating over the road, and to permit the bitumen to be absorbed into the road material to as great an extent as possible.

This treatment is for the most part limited to the treatment of roads already built, although sometimes employed in new construction. For old roads which are in good surface, it forms a convenient method of treatment,

without renewing the surface. The details of the method are discussed in Art. 49.

(b) *Penetration Method.* In constructing a bituminous macadam surface by this method, the macadam is first placed in the ordinary manner, but without applying the binder to the surface layer of stone. A coating of bitumen is then given to the surface, and allowed to flow into the voids in the stone, after which stone chips are applied and rolled into the surface. A second coating of bitumen is usually applied and covered with additional chips, or screenings, and the whole rolled to a smooth surface.

This method is extensively employed in the United States, the materials used and the details of construction varying widely in different parts of the country. These are discussed in Art. 50.

(c) *Mixing Method.* This consists of using for the surface layer, bituminous concrete, obtained by mixing hot bituminous binder with the macadam stone. The lower course of the road is usually formed of water-bound macadam, the surface material, which has been previously mixed, is then placed to the proper thickness and rolled to a smooth surface. Sometimes the stone is heated before mixing with the bitumen, and sometimes used cold. Commonly a layer of stone chips is rolled into the surface of the concrete, and frequently a paint coat of bitumen is also applied, covered with sand or stone chips, and rolled to a finished surface.

This method is largely used in England and to a less extent in the United States. It is applied mainly to new construction, although sometimes used in resurfacing old roads. The methods used in construction are discussed in Art. 51.

In the construction of city streets, bituminous concrete is frequently used, which is obtained by more care-

ful and elaborate methods, closely graded aggregates being employed, sometimes with cement concrete foundation. This more expensive construction is not classed under the head of bituminous macadam, but is commonly known as bitulithic pavement and is discussed in Chapter IX.

(d) *Gladwell Method.* This method was developed in England as a means of resurfacing old roads, but is also used in new construction. It has not been used to any extent in the United States.

A foundation coarse of water-bound macadam is first formed, or the surface of the existing macadam is smoothed and cleaned. A light layer (about $\frac{3}{4}$ inch) of tarred chippings is then spread, and upon this the road metal is placed and rolled into the chippings. On top of the macadam surface so formed, a second layer of the tarred chippings is spread and rolled into the voids in the surface stone, with the object of thoroughly filling the macadam stone with the matrix. The surface is then sealed by a light coating of hot tar preparation, which is covered with screenings and rolled.

According to the specifications of the inventors of the method, the matrix is composed of clean dry granite screenings mixed warm with a special tar preparation, while the aggregate is broken to nearly uniform size (2 ins. to $2\frac{1}{4}$ ins.). The good results which have been obtained with these roads in England, have been attributed* to the excellence of the materials used in forming the matrix rather than to the method of construction.

(e) *Rock Asphalt Macadam.* The method of constructing these roads is to form the macadam surface in the same manner as for water-bound macadam, and then, in place of the usual binding material, to apply

* Smith, Dustless Roads, Tar Macadam, London, 1909.

a top dressing of ground rock asphalt and roll to a smooth surface. The surface layer of stone is thoroughly rolled, without binder, to a thickness of about 2½ or 3 inches, this is then covered with a thin layer, about ½ inch, of the rock asphalt, which is rolled thoroughly into the voids in the stone. A thicker layer, about 1 inch, of the rock asphalt is then placed and rolled to a smooth surface. The stone for the surface layer is usually of rather uniform size, 1 inch to 2 inches, and must be quite dry when used. A thin cushion of the rock asphalt should be left over the surface upon completion, to be forced into the voids in the surface metal under the action of traffic, although it is desirable that the wear of traffic come upon the stone of the surface course and the asphalt serve purely as binder.

When the asphalt is convenient to the work and the cost of transportation is not too great, these roads may often be economically constructed and give good service. Rock asphalt for this purpose should contain about 7 to 10 per cent of bitumen. Kentucky asphalt has been used to considerable extent for this purpose very successfully.

ART. 44. BITUMINOUS MATERIALS.

The term bitumen is used to designate a class of substances, consisting of a mixture of various series of hydrocarbons and possessing certain physical and chemical properties by which they are defined. Several groups of hydrocarbons are commonly present in each sample of bitumen, and the range of possible mixtures is very great, so that considerable confusion exists concerning the assification of the various substances included under this designation, as well as in defining the limits within which substances may be considered to be bitumens.

Mr. Prevost Hubbard has made a very careful study of these materials, and gives the following definitions: * "Bitumens may be described as consisting of a mixture of native or pyrogenetic hydrocarbons and their derivatives, which may be gaseous, liquid or solid, but if solid, melting more or less readily upon the application of heat, and soluble in chloroform, carbon bisulphide and similar solvents."

Bitumens being thus a mixture of various hydrocarbons in differing proportions, have no fixed compositions, and vary widely in properties according to the characters and amounts of the hydrocarbons of which they are composed. They are divided into natural bitumens and artificial bitumens. *Natural bitumens* are those which occur in nature as mineral bitumens. *Artificial bitumens* are those which are formed by the distillation of certain other mineral substances known as pyrobitumens. The distillation of natural bitumens also gives rise to other bitumens of differing characteristics, and these, particularly those left as residues after distillation, are also designated artificial bitumens.

NATIVE BITUMENS.

Bitumens occur in nature as natural gases, petroleums, malthas and asphalts, beside a number of other materials which gradually merge into the pyrobitumens.

Petroleums are liquid bitumens and are divided into paraffine oils, cylic or asphaltic oils and semi-asphaltic oils. The paraffine petroleums consist mainly of the paraffine hydrocarbons (C_nH_{2n+2}) and are of little importance as road materials, showing no permanence as dust preventives and no binding properties in the road. The asphaltic petroleums are characterized by the poly-

* Dust Preventives and Road Binders, New York, 1910.

methylene hydrocarbons and when distilled yield a residue similar in character to asphalt. The semi-asphatic oils consist of a mixture of the paraffine hydrocarbons with those of the asphaltic oils.

Asphalts are solid bitumens composed of hydrocarbons of the same characters as those of the asphaltic oils, but with the lighter and more volatile parts removed. This class includes the true asphalts and a number of similar materials, such as glance pitch, manjak and gilsonite.

Malthas are heavy oils intermediate between the asphaltic petroleums and the asphalts. They are similar in character to the fluid residuums derived from asphaltic petroleums, but, as they contain more of the volatile hydrocarbons, may be hardened by exposure to the air, or by heat, becoming an artificial asphalt. These materials have been produced to some extent in California and seem to form desirable road materials.

ARTIFICIAL BITUMENS.

The artificial bitumens which are of importance as road materials are crude tars, residues from the distillation of petroleums and residues from the distillation of tars. The crude tars include water-gas tars, and coal tars. Residues from the distillation of petroleum are either residual oils or residual pitches. The residual oils are obtained by removing all of the more volatile oils, including the lubricating oils. These may be used as road oils, when derived from asphaltic petroleum, and are also employed as fluxing agents in preparing asphalts for use in pavements. Residual pitches are obtained when distillation is carried far enough to leave a solid residue. If derived from asphaltic oil these may give good road materials.

The residues derived from the distillation of tars are known as dehydrated tars, refined tars and tar pitches. Dehydrated tar is that from which the water has been removed. Tar pitches are formed when distillation leaves solid or semi-solid residues. Refined tars are products intermediate between dehydrated tars and pitches. All of these materials may be of use as road binders when carefully prepared from coal-tar.

ART. 45. PETROLEUMS.

Petroleums, or mineral oils, are widely distributed throughout the earth. They occur in generous quantities in many parts of the United States, the oils of different localities varying widely in character.

The *Applachian oil field* lies on the west side of the Alleghany Mountains, through Western Pennsylvania, West Virginia, Kentucky and Tennessee. These oils, particularly those known as Pennsylvania grade, are rich in paraffines, and contain practically no asphaltic hydrocarbons. They are commercially the most valuable of the petroleums, on account of the large amount of illuminating oils derived from them, but are of little value for road purposes, as the base retained after evaporation of the more volatile constituents is lacking in binding properties.

The *Ohio-Indiana oil field* includes the oils of Western Ohio and Indiana. They, like the Pennsylvania oils, are of little value for road purposes, but they differ from the Pennsylvania oils in containing considerable sulphur and in giving a less amount of illuminating oils.

The *Illinois oil field* covers the oil districts in Illinois and a part of Northern Kentucky. These oils vary considerably in character, and seem to be of less com-

mercial value than the oils of the more eastern fields. Some are quite similar to those of the Ohio-Indiana field, while others contain considerable percentages of the asphaltic hydrocarbons and approach the semi-asphaltic oils in character. The recent development of this field has been very rapid, and large quantities of these oils are now being produced.

The *mid-continent oil field* comprises the Kansas and Oklahoma oils and those of Northern Texas. These oils, like those of Illinois. are quite varied in character. They contain considerable quantities of the asphaltic hydrocarbons as well as those of the paraffine series and may be classed as semi-asphaltic. Very large quantities of petroleum are produced in this district, which are sold at lower prices than any of the others.

The *Gulf oil field* includes Louisiana and Texas. These oils usually contain more asphaltic and less paraffine hydrocarbons than the Illinois or Kansas oils. They yield residues superior to the others as road materials, because of possessing better binding properties.

The *California oil field* produces oils composed mainly of asphaltic hydrocarbons. These oils vary widely in density, the lighter ones being less suitable for road purposes, unless refined, on account of the greater percentages of volatile hydrocarbons present. When distilled, they yield residues similar in character to asphalt, which have been employed for pavements under the name of artificial asphalts.

Crude petroleums are frequently used as dust layers on roads, and all classes of oils have been tried for this purpose. The paraffine oils are of use for very temporary effect only. These oils are also objectionable on account of the sticky black mud frequently formed in wet weather. The semi-asphaltic oils of the mid-continent and Texas

fields are more satisfactory, not possessing the objectionable properties of the paraffine oils, but the effect of these when crude oil is used is also lacking in permanence and does not exert a binding effect upon the road surface. The asphaltic petroleums of the California field have frequently given good results when used in a crude state, binding together the material of the road surface, and causing it to gradually harden. The large quantity of excellent material available for such use at low cost has led to the development of the oiled earth road in California (discussed in Art. 29) as well as to the extensive use of oiled macadam roads.

Petroleum Residuums. The character of the residue obtained by the distillation of petroleum depends upon the kind of petroleum used and the extent to which the distillation is carried. The residuums may be either fluid or solid, according to the extent to which the lighter oils have been driven off.

The fluid residues from the semi-asphaltic petroleums are largely used as road oils, under the name of *asphalt oils*. Many of these possess good binding properties, and are satisfactory materials for the purpose. These oils are also frequently employed as fluxes for the solid bitumens in preparing paving mixtures.

The binding properties of road oil depend upon the presence of the heavy asphaltic hydrocarbons, which possess adhesive properties and will remain in the road after the evaporation of the lighter hydrocarbons. Oils for this purpose therefore should contain a considerable percentage of the heavy hydrocarbons (bitumen insoluble in 88 degree naphtha) and should have a low percentage of paraffine scale.

The solid residuums from asphaltic or semi-asphaltic petroleum are commonly known as *oil asphalts*, and are

employed in much the same manner as the natural asphalts. These materials vary greatly in character, depending upon the care used in preparation as well as the petroleum from which they are made.

Blown oils are semi-solid residuums prepared by blowing air through a fluid residuum, causing a thickening of the oil. The oxygen of the air combines with a part of the hydrogen of the hydrocarbons, thus producing a change in the characters of the hydrocarbons.

These oils have been used to considerable extent for road purposes when made from semi-asphaltic petroleums, and, when carefully prepared, have shown good results.

ART. 46. SOLID NATIVE BITUMENS.

The solid native bitumens which are of interest in paving or road work include the asphalts, gilsonites and grahamites. These bitumens consist, like the petroleums, of natural mixtures of hydrocarbons, but are composed mainly of the heavier hydrocarbons and occur as solids. Mr. Clifford Richardson divides * the hydrocarbons occurring in these bitumens into four classes which he calls:

Petrolenes, including those hydrocarbons which are volatilized at 325 F. in 7 hours.

Malthenes, including the oils which are soluble in 88° Baumé naphtha.

Asphaltenes, including the heavier hydrocarbons not soluble in naphtha but soluble in cold carbon tetrachloride.

Carbenes, including hydrocarbons soluble in carbon bisulphide, but insoluble in cold carbon tetrachloride.

This classification is also frequently extended to the

* The Modern Asphalt Pavement, New York, 1905.

hydrocarbons occurring in the petroleums, which are very similar in character.

The solid native bitumens can only be used for road purposes by being combined with fluid bitumens to bring them to proper consistency. In the use of these materials as road binders, petroleum residuum is employed as a flux to form asphaltic cement in the same manner as in the construction of asphalt pavement (see Art. 67).

The asphalts consist mainly of malthenes and asphaltenes, usually mixed with a certain amount of mineral matter, and need to be refined before using to remove water and impurities they may contain. They are produced to only a limited extent in the United States, and while used largely in the construction of asphalt pavements, are employed very little for bituminous macadam roads on account of the greater cost as compared with petroleum and tar products.

Gilsonite differs from asphalt in being more largely composed of unsaturated hydrocarbons, and less soluble in naphtha. It occurs in Colorado and Utah,and is very nearly pure bitumen, containing very little mineral matter. It is used to some extent in the construction of asphalt pavements, as well as in macadam road construction for which, when properly prepared, it seems a desirable material.

Grahamite differs from asphalt in being composed mainly of asphaltenes and carbenes, as it is but slightly soluble in naphtha, and much less soluble in carbon tetrachloride, than the other asphaltic materials. It has been used in asphalt pavements.

These materials and the methods of using them are discussed more fully in Chapter IX.

Rock Asphalt is the name applied to sandstone or limestone impregnated with bitumen. These materials

differ widely in the character of the rock, as well as in the kind and quality of the bitumen with which it is impregnated. It may vary from sand, in which the individual grains are held together only by the bitumen, to solid rock in which the pores are filled with bitumen.

Some of these materials are largely used for asphalt pavements (see Chapter IX). They are also used to some extent as fillers in bituminous macadam construction. Materials of this character are somewhat widely distributed over the United States, but on account of the wide variation in the material, much of it is not suitable to this use. Good results have been obtained in the use of Kentucky rock asphalt, consisting of sandstone impregnated with about 6 to 8 per cent of rather soft bitumen, which hardens upon exposure to the air, through the volatilization of some of the light oils.

ART. 47. TAR PRODUCTS.

The coal tar used in road work is obtained as a by-product either in the manufacture of illuminating gas or in the burning of coke. Very large quantities of tar are produced in the United States, although until quite recently, the value of tar has been so small that it has been considered a necessary evil, and but little attention given to the character of the tar produced.

Tars are made up of a mixture of hydrocarbons of extremely variable character, and it is customary to classify these as light oils (volatilizing below 170° C.), heavy oils (volatilizing between 170° and 270° C.), and pitch, which is the residue not volatilized. The light oils are also frequently divided into those which volatilize below 110° C. and those volatilizing between 110° C. and 170° C. Crude tars commonly contain some

ammoniacal water, which is included in the distillate at 110° C., and is objectionable in tars for road work, if present in appreciable quantities.

The value of tar for road purposes depends upon the method and care used in its production, as well as upon the character of the coal from which it is obtained. The temperature at which the coal is distilled has an important effect upon the quality of the tar, as the oils formed at different temperatures differ considerably in character.

In the manufacture of coal gas, bituminous coal is heated in a retort until the more volatile parts are driven off, leaving a residue of coke. The gas and tar are separated by passing the distillate through water under which the tar is condensed, the gas passing on through a condenser and other apparatus in which the remainder of the tar is removed. The chemical changes which occur in the distillation of coal are but little understood. They consist in a breaking up of the compounds of which the coal is composed and the formation of new combinations, which depend upon the temperature at which the distillation takes place. At a high temperature the dissolution is more complete, a greater quantity of gas being formed, leaving less of the heavy oils in the tars, which contain more solid bitumens and more free carbon than those formed at lower temperatures. The tars formed at high temperatures are not so desirable for road purposes on account of the lack of a sufficient quantity of the heavy oils, and because of an excess of free carbon.

Coke-oven tar is obtained from coal in much the same manner as that produced in the manufacture of gas, excepting that the chief object is to produce coke instead of gas. Large quantities of tar are now obtained from this source, but only a comparatively small portion of the coke ovens in use are constructed with a view to

saving the by-products, and in most instances the gas and tar are allowed to escape and no effort made to save them. The great increase in the uses of tar and tar products is, however, causing a change in this respect, and much greater quantities of tar may reasonably be expected in the future from this source. These tars are similar to those from gas works, but are usually formed at lower temperatures, and thus contain larger percentages of heavy oils and less free carbon.

Water-gas tars are produced by the decomposition of petroleums, or petroleum distillates, in the carburetting of water gas. The petroleum oils are broken up into light oils, or gases, which impart illuminating value to the water gas, and heavier oils, which are condensed as tar. These tars are lighter materials than the coal tars, containing a larger percentage of heavy oils and less of pitch residue. They are usually low in free carbon, do not contain ammonia water, and frequently are desirable materials for use as dust layers in road work.

REFINED TARS

Tars, like petroleums, are refined by fractional distillation, the character of the residual depending upon the extent to which the lighter oils have been driven off, as well as upon the nature of the original tar. In refining, the tar is divided into several fractions by separating the distillates between certain temperatures, and these fractions are again distilled to separate into desired products, such as benzol, naphtha, carbolic acid and naphthalene.

The residue may be liquid or solid according to the temperature to which the distillation has been carried, and the extent to which the heavy oils have been removed.

The semi-solid and solid residues are termed pitches and are classified according to the temperature required to liquefy them. Sufficient heavy oil must be left in the residue to render it semi-fluid if it is to be used as a road binder. The solid residues are, however, sometimes used in the same manner as the solid native bitumens, by fluxing them with other oils.

In some instances, when the distillation is carried so far as to remove the heavy oils, leaving a solid residue, parts of the heavy oils are returned to the residuum before it cools, thus reducing it to a semi-fluid condition, and forming what is known as a *cut-back product.* Usually, where this method is followed, the naphthalene is removed from the heavy oil, which is an advantage to the use of the residual for road work.

DEHYDRATED TARS

Sometimes when tars are not to be distilled for the separation of the products obtained from the oils, they are prepared for use in road work by heating sufficiently to drive off the water and some of the light oils and are then known as dehydrated tars. These tars are superior to crude tars, as the presence of water is objectionable in tars for use as road binders. This is particularly the case with those containing ammoniacal water.

ART. 48. TESTS FOR BITUMINOUS MATERIALS.

On account of the wide variation in character of bituminous materials which may be available for road work, it is very essential that tests be applied for the purpose of determining the properties of the various bitumens and their suitability for use in construction.

Considerable variation exists in the tests applied for this purpose by various authorities, as well as in the methods of conducting them, and but little has been accomplished towards standardizing such work. The tests here enumerated are all used to some extent and are of value for some materials, but all of them are not applicable to any one material.

SPECIFIC GRAVITY.

The determination of specific gravity is nearly always important. The method of determination must of course depend upon the consistency of the bitumen. As the specific gravity of bitumens varies with the temperature, it is essential that the determination be made at standard temperature, and 25° C. (77° F.) is ordinarily employed for the purpose. It is customary to state the specific gravity in terms of that of water at the same temperature.

When the bitumen is quite liquid, a hydrometer graduated to read the specific gravity directly is the most convenient method and is commonly employed. When the materials are too viscous to permit the use of a hydrometer, it is usual to employ a picnometer. Mr. Hubbard describes * a form of picnometer specially suited to this work, while Sommer has devised† a specific gravity apparatus intended for semi-solid and solid bitumens by suspending a cup containing a definite volume of the bitumen from a hydrometer, the stem of which is graduated to read the specific gravity.

A knowledge of the specific gravity of a bitumen is useful both as assisting in determining the character of the bitumen and in indicating the treatment to which it may have been subjected. Crude paraffine petroleums

* Dust Preventives and Road Binders, New York, 1910.

† Proceedings American Society for Testing Materials, 1909.

vary in specific gravity from about 0.75 to 0.85, and is usually lower than asphaltic petroleum, which may have a specific gravity of about 0.92 to 0.97, the semi-asphaltic oils being between the two. Residual oils are heavier than crude oils of the same character, the difference being to some extent indicative of the extent of distillation to which the oil has been subjected. The specific gravity of coal tar is largely influenced by the amount of free carbon it contains. Refined tars suitable for road purposes usually vary in specific gravity from about 1.15 to 1.22, the higher value representing a rather large percentage of free carbon.

COMPOSITION OF BITUMINOUS MATERIALS.

In all examinations of bituminous materials it is necessary to determine the percentages of bitumen and of other organic and inorganic matter in the materials. For petroleums and solid native bitumens it is customary to determine the quantity of organic matter not classed as bitumen, and the percentage of inorganic material present. For tars, it is usually necessary to determine also the percentage of free carbon.

In testing native bitumens, the light oils are separated from the heavy ones by testing the solubility in 86° Bé. or 88° Bé. naphtha, and with asphalts the carbenes are separated by the solubility in cold carbon tetrachloride. In the examination of tars the light and heavy oils are separated by fractional distillation.

Total Bitumen. All organic matter which is soluble in carbon bisulphide is classed as bitumen. Methods of making the test as adopted by the American Society for Testing Materials are given in Art. 68. The following more rapid method, which has also been recommended

by a committee of the same society, is more commonly used in testing road materials.

"From 1 to 10 grams of the water-free material (depending upon the amount of bitumen present) is weighed into a 150-c.c. Erlenmeyer flask, the tare of which has been previously ascertained, and treated with 100 c.c. of carbon disulphide. The flask is then loosely corked and shaken from time to time until practically all large particles of the material have been broken up, when it is set aside for not less than 15 hours. At the end of this time the contents of the flask are decanted off upon a weighed Gooch crucible fitted with long-fiber amphibole asbestos filter. The residue remaining in the flask is then washed with 50 c.c. of carbon disulphide, allowed to settle, and decanted as before, the insoluble matter being finally brought upon the filter and washed with 100 c.c. carbon disulphide, or until the washings are practically colorless. The filter and contents are then dried at 125° C., cooled, and weighed. Should any residue remain in the flask, it is also dried and weighed, and this weight added to that of the residue in the crucible. The filtrate should be burned off and ignited to an ash, and the weight of the ash thus obtained added to that of the insoluble residue. The weight of the total residue deducted from that of the original material gives the weight of bitumen soluble in cold carbon disulphide. In case of tars and pitches the percentage of insoluble residue, determined as above, minus that of any ash which may be found by igniting a separate sample, is reported as free carbon."

Free Carbon. In the examination of coal tars, or tar products, the determination of free carbon is a matter of importance, as this is usually considered an undesirable constituent in a road tar, and limits are commonly set

in specifications to the percentage which may be present. A method of determining free carbon is given above in the test for total bitumen.

Fixed Carbon. The term *fixed carbon* is applied to the residual coke resulting from burning bitumen in a closed crucible, and in the absence of oxygen. The test is frequently used in the examination of petroleum residuums and asphalts to indicate the extent to which these materials contain the heavier hydrocarbons of asphaltic character. A method of conducting the test as recommended by a Committee of the American Society of Civil Engineers is as follows:

"About 1 gram of the compound is weighed into a platinum crucible $1\frac{1}{8}$ to $1\frac{1}{2}$ inches high. The crucible with the lid on is heated, first gently, and then until no more smoke and flame issues between the crucible and the lid. It is then heated $3\frac{1}{2}$ minutes in the full heat of the burner; then cooled and weighed. The crucible lid is then removed and the crucible and contents allowed to remain in the full heat of the burner until the carbon is burned off, and then weighed again. The difference between these two weights is the fixed carbon.

Naphtha Soluble Bitumen. Petroleum and asphalt bitumens are commonly tested as to their solubility in naphtha derived from paraffine petroleum. This test is made to determine the relative proportions of the heavier hydrocarbons (asphaltenes), which are insoluble, and of the oils (malthenes), which are soluble in the naphtha.

Naphtha for this purpose is commonly required to have a density of 88° Bé. and a boiling-point between 40° C. and 55° C. Some authorities prefer to use naphtha of 86° Bé. gravity, on account of it being more easily obtainable, although it dissolves a little more of the bituminous material and is not quite so satisfactory for

this reason. In reports of this test, the density of the naphtha, and temperatures between which it distills should always be given, and results should be stated in terms of total bitumen. This test is conducted in the same manner as that for solubility in carbon disulphide.

Distillation Test. This test is made upon tars to separate the oils which distill at different temperatures, and determine the proportions of each contained by the tar.

The test is made by heating the tar in a retort, and collecting the distillate in a condenser pipe, which is changed as each temperature is reached in the distillation, and the distillate cooled to standard temperature and its volume measured or its weight taken.

Mr. Hubbard recommends * the use of temperatures 110° C., 170° C., and 270° C., as points of division. The fraction which distills over up to 110° C., includes the water and ammonia compounds, with certain light oils. These separate in the condenser and may be separately measured. The distillates between 110 C. and 170° C., are regarded as light oils; those between 170 C. and 270° C as heavy oils, and the residue as pitch.

In tars for road binders, water and ammonia compounds should not be present in appreciable quantities, but a small percentage of light oils is desirable, and if the tar is to be used as a binder in construction of bituminous macadam, it should contain at least 50 per cent of material not volatilized at 270° C.

TESTS FOR CONSISTENCY.

For the purpose of determining the consistency of bituminous materials, three tests are commonly employed;

* Dust Preventives and Road Binders, New York, 1910.

the viscosity test for fluid bitumens, the float test for materials too viscous for the viscosity test, and the penetration test for solid materials.

Viscosity Test. Viscosity is measured by determining the time required for a given volume of the liquid under test to pass through a small opening, and comparing with the time required for the same volume of water, at standard temperature (25° C.), to pass the same opening.

The Engler viscosimeter is commonly employed for this purpose. It consists of a covered brass vessel with a conical bottom, to which is fitted a vertical outflow tube 20 mm. long, with a diameter at top of 2.9 mm. and at bottom of 2.8 mm. The tube is closed by a hard-wood stopper, which extends through the cover of the vessel. The vessel sets in a bath of heavy oil which is heated by a ring burner underneath. A measuring flask is placed beneath the outflow tube to receive the liquid as it passes through the opening. The time required by a given volume of the bitumen at the desired temperature to pass the opening is measured, and the viscosity computed by dividing the time so obtained by the time required for the same volume of water at 25° C. to pass through.

Float Test. This test is sometimes applied to materials too viscous for the Engler viscosimeter, The New York Testing Laboratory Float Apparatus * is employed in making the test. It consists of a float or saucer, with an opening in the bottom, into which a brass collar may be screwed. The collar is filled with the bitumen (softened by heat), and then placed in ice water at 41° F. for 15 minutes. The collar is then screwed into the float, which is placed upon the surface of water at 90° F.

* See Engineering Record, Vol. LIX, 584.

When the bitumen softens, water is admitted to the saucer and the apparatus sinks. The time in seconds required for the apparatus to sink is taken as the consistency.

Penetration Test. For determining the consistency of solid or semi-solid bitumens, the penetration into the bitumen of a standard needle, under a constant weight, is measured. The tests are made at standard temperature and for definite times. Methods of making the test for road bitumens are the same as those employed for asphalt paving mixtures, which are described in Art. 69.

The American Society for Testing Materials has recommended * the following as standards for this test:

"The penetration of bitumen shall be the distance expressed in hundredths of a centimeter that a No. 2 needle will penetrate into it vertically without friction at 25° C. under a stated weight applied for a stated length of time, the factors of weight and time being determined as follows:

"The material shall first be tested for five seconds under a weight of 100 grams. If this results is less than ten, the penetration shall be determined under a weight of 200 grams applied for one minute; if between 10 and 300, the penetration shall be determined under a weight of 100 grams applied for 5 seconds; if greater than 300, the penetration shall be determined under a weight of 50 grams applied for 5 seconds. In every case the factor of weight and time shall be stated when reporting the penetration, and whenever possible to obtain both readings, the penetration under a 100-gram weight for 5 seconds and under the modified weight and time shall both be reported. When testing material softer than 100 penetration, a containing receptacle not less than 1¼ inches in diameter shall be used.

* Proceedings, American Society for Testing Materials, Vol. XI, p. 247.

"It is recommended that the penetration may be determined at 0° C. (32° F.) and 46° C. (114.8° F.) in addition to the 25° C. (77° F.) test."

EVAPORATION TEST.

This test is made for the purpose of determining the extent to which the material will give off the lighter hydrocarbons when heated. The following method of making the test is recommended by the American Society for Testing Materials:

"The loss on heating of oil and asphaltic compounds shall be determined in the following manner: Twenty grams of the water-free material shall be placed in a circular tin box with vertical sides, measuring about 2 cm. in depth by 6 cm. in diameter, internal measurement. The penetration of the material to be examined shall, if possible, be determined at 25° C. and the exact weight of the sample ascertained. The sample in the tin box shall then be placed in a hot-air oven (New York Testing Laboratory oven without fan), heated to 163° C. (325° F.) and kept at this temperature for 5 hours. At no time shall the temprature of this oven vary more than 2° C. from 163° C. When the sample is cooled to normal temperature, it shall be weighed and the percentage of loss by volatilization reported. The penetration of the residue shall then, if possible, be determined at 25° C. as upon the original material, and the loss in penetration found by subtracting this penetration from the penetration before heating. In preparing the residue for the penetration test it shall first be heated and thoroughly stirred while cooling."

When this test is applied to solid bitumens, it is intended to indicate the possibility of changes taking place in the

character of the bitumen through evaporation, during application or subsequent to use in the road. It is common, when so using the test, to make penetration test of the residue from the evaporation test as well as of the original bitumen.

MELTING POINT.

The temperatures at which bituminous materials become sufficiently soft to flow, are frequently determined and are known as the melting-points of the materials.

The following method of making the test is recommended by a Committee of the American Society of Civil Engineers:

Melting-point of Residue from Evaporation. The material whose melting-point is to be determined, is melted and poured into a mold that will make a ½-inch cube. A No. 10 gauge wire about 6 inches to 8 inches long is bent at right angles for a length of ¾ inch at one end and the center of the cube is placed on this end so that one of the diagonals of the vertical face of the cube is parallel to the long part of the wire. Take a bottle of a size about 2 inches in diameter and 4 inches high and place a piece of white paper in the bottom of it. Pass the long part of the wire through the cork of the bottle so that the lower edge of the cube will be within 1 inch of the bottom of the bottle. Also put a thermometer through the cork so that the bulb is opposite the cube. Place the bottle in a water or oil bath and raise the temperature of the bath at a rate of 3 to 6° C. a minute. The melting-point of the material is the temperature of the thermometer inside the bottle at the time that the material touches the paper in the bottom of the bottle.

PARAFFINE TEST.

For the determination of the amount of paraffine scale present in bitumens, the following method is usually employed:

Paraffine. One hundred grams or less of the compound is distilled rapidly in a retort to dry coke.

Five grams of the well-mixed distillate is treated in a 2-ounce flask with 25 c.c. Squibbs absolute ether; after mixing thoroughly, 25 c.c. Squibbs absolute alcohol is added and the flask packed closely in a freezing mixture of finely crushed ice and salt for at least 30 minutes. Filter the precipitate quickly by means of a suction pump, using a No. 575 C. S. & S. 9-cm. hardened filter paper. Rinse and wash the flask and precipitate (with 1 to 1 Squibbs alcohol and ether mixture cooled to $-17°$ C.) until free from oil (50 c.c. of wahing solution is usually sufficient). When sucked dry remove paper, transfer waxy precipitate to small glass dish, evaporate on steam bath and weigh paraffine remaining on dish.

Calculation. Weight of paraffine divided by weight of distillate taken and multiplied by per cent of total distillate used from original sample, equals per cent of paraffine.

ART. 49. SURFACE TREATMENT.

The kinds of bitumen employed and the details of application vary considerably in the practice of different engineers who construct roads by this method. In all cases, it is insisted that, before the application of the treatment, the surface of the macadam road shall be in smooth, firm condition, free from dust and dirt. Where heavy oils, or tars, are being used, dust will prevent penetration into the surface of the road, and holes, or

depressions, will cause an accumulation of oil, resulting in soft spots in the surface.

The method most largely employed is, after cleaning the road surface of dust, to spread a coating of hot oil or tar over the surface which is then covered with a layer of sand or stone chips to absorb the surplus bitumen and rolled to a smooth surface. The tar or oil is frequently spread by the use of flat-nosed watering pots, or ladles, or sometimes by the use of hose attached to the kettles. The bitumen is then broomed into the surface in order to secure a uniform coating. This is accomplished by laborers with stiff brooms, who follow the distributors, and brush any excess of oil or tar upon uncovered spaces.

On large work, it is more economical to distribute the bitumen from tank wagons, in which the oil is heated and which are arranged with various forms of distributors to apply the hot oil to the surface. It is necessary that a uniform pressure be maintained on the distributors, and a number of devices have been tried for this purpose, most of which have not been used to sufficient extent to fully demonstrate their value. The most successful distributors seem to be those in which the bitumen is sprayed upon the road by compressed air, and a number of different appliances of this kind are now on the market. Some of these, while capable of making a good distribution of oil, are liable to quickly get out of order, and in some instances it has been found more economical to distribute by means of hose attached to the tank wagons. For this purpose, a nozzle which atomizes the oil is desirable, the distribution being made under a constant pressure.

After the oil has been spread, it is desirable that it be allowed several hours for absorption into the road surface before applying the layer of chips. Very com-

monly, however, the chips are immediately applied, and rolled. Sometimes a second or even a third application of bitumen and chips is made to the surface, producing a layer of oiled material on top of the macadam surface. When such is the case the material used must possess sufficient stability not to become soft in wet weather.

The bitumen used for surface treatment may be petroleum residuum, or tar, so viscous as to require heating before application. The heating is commonly done in kettles or tanks, mounted on wheels. A temperature of about 100° C. is usually required, although sometimes harder bitumens are employed, for which somewhat higher temperatures are necessary.

The quantity of bitumen required for a surface treatment with heavy oil depends upon the character of the road metal, and extent to which the oil may be absorbed, as well as upon the method of treatment adopted. The quantities used vary from about ¼ to ¾ gallon per square yard of surface, and the cost from about 5 cents to 12 cents per square yard.

The method of surface treatment used in the construction of telford streets in St. Louis by Street Commissioner Travilla is shown by the following extracts from his 1911 specifications:

MACADAM OR SECOND COURSE.

"When the telford foundation has thus been formed, there shall be spread a layer of clean, hard limestone macadam, free from clay, earth or rubbish; which layer, when thoroughly compacted, shall be 4 inches in depth. The stone shall be so broken that all will pass a 3-inch ring and none will pass a 1½-inch ring. The stone shall be broken to conform to the above requirements before being brought on the line of the work.

This course shall be thoroughly consolidated by a roller, as above specified, and any unevenness in the surface shall be corrected before spreading the limestone screenings. The macadam course having been finished, the interstices of the stones shall be completely filled with clean macadam screenings, containing 50 per cent dust. This layer shall then be flooded and rolled until it is compact and solid, and ceases to creep under the action of the roller. Rolling shall be continued until the screenings and water flush to the surface upon all parts of the roadway. The surface of the macadam shall be broomed immediately after rolling, leaving the clean stone projecting; the voids, however, to be thoroughly filled.

ROAD OIL.

"When the macadam surface, as above prepared, has thoroughly dried out to the satisfaction of the street commissioner, hot road oil shall be spread over the same to the amount of ½ gallon per square yard of surface. The oil, as below specified, shall be applied to the roadway surface at a temperature of at least 250° F. Proper sand barricades shall be constructed along the edge of the granitoid gutters to prevent the oil from flowing into the same. If the street commissioner deems it necessary, he may require the macadam surface to be thoroughly hand-broomed and to be lightly sprinkled with water before the oil is applied.

"The specific gravity of the road oil shall not be less than 0.959 (16.0° Bé. at 60° F.).

"The loss upon heating a 20-gram sample of the oil in a vessel 2¼ inches in diameter and 1½ inches high, with vertical sides, for 5 hours at 325° F. (163° C.) shall not exceed 3 per cent by weight. It shall not con-

tain more than ½ per cent by weight of matter insoluble in carbon bisulphide."

The following method of treating the surfaces of finished macadam roads is given * by Mr. Charles W. Ross, as used at Newton, Mass:

"Several macadam-surfaced streets, having varying grades up to a maximum of 9 per cent, and subjected to heavy horse-drawn and automobile traffic, were selected for the liquid asphalt treatment. The method used was as follows: A quantity of sand was heated to a temperature of about 200 ° F., dumped in a pile, and leveled. The asphalt was poured over the hot sand in the proportion of 1 gallon to each cubic yard of sand, and then the whole mass was turned with shovels or mixed in a concrete mixer. (The latter being preferable on account of cost.) This work was done at the pit. The mixture was teamed to the work and spread on the roadway to a depth of less than ¼ inch, being raked even with 14-tooth wooden rakes. Rolling was not considered necessary and the street was kept open for traffic at all times. The cost of this treatment was about 3 cents per square yard. It has the advantage of leveling and building up the surface of the road, each new application providing a new wearing surface. This work has remained in perfect condition without further expense since the summer of 1909."

Surface treatment of macadam roads with bituminous materials has been quite largely used in the United States during the past few years. In general, when road surfaces in good condition have been properly treated with good materials, the results have been fairly satisfactory, particularly when required to resist automobile traffic. In some instances, however, these roads do not

* Transactions, American Society of Civil Engineers, Vol. LXXIII, p. 47.

seem so satisfactory when the traffic is mainly horse-drawn, which traffic may cut through the oiled layer upon the surface and cause the road to rut.

ART. 50. PENETRATION METHOD.

Roads constructed by the penetration methods by different engineers vary considerably in details. In most instances, the bottom course is constructed in the same manner as for water-bound macadam, the voids being completely filled with sand or screenings, and rolled to a hard surface. After completing the foundation course, the second course of road metal is placed. This may consist, when hard rock is employed, of stone varying in size from about ½ inch to 1½ inches, or, when limestone is used, from about 1 inch to 2½ inches in diameter, the road metal is placed to the proper depth (usually 2½ or 3 inches) and rolled to an even surface. The hot bitumen is then poured over the surface, and allowed to run into and coat the stone composing the surface course. In some instances a light coating of stone chips is used, to partially fill the voids, before the bitumen is applied. The bitumen must be quite fluid at the temperature of application, in order to run into the surface material and thoroughly coat the stone, About 1½ gallons of bitumen per square yard are usually required. The surface is next covered with a coating of stone chips, which are rolled into the surface. Upon completion of the rolling, any surplus fine material should be swept from the surface before adding the paint coat, which consists in pouring about ⅓ or ½ gallon of bitumen per square yard over the surface, covering with screenings, and rolling to a finished surface.

The bitumen may be applied to the surface by the same

methods as are used in surface treatments, although some of the automatic distributors do not work so well over these comparatively rough surfaces as on the finished macadam.

The method of construction used by the Illinois Highway Commission is shown by the following extract from their 1911 specifications:

SPREADING SECOND COURSE OF STONE.

"The broken stone for the second course is not to be spread before the first course has been completed and shoulders made as herein specified. The second course shall be of 2½-inch stone and shall be spread to compact under rolling to the thickness shown on the plans.

HARROWING SECOND COURSE OF STONE.

"After the second course of stone has been spread, it shall be harrowed as hereinbefore described for the first course of stone. (See p. 148).

ROLLING SECOND COURSE OF STONE.

"After the broken stone for the second course has been spread and harrowed to the required thickness and has a proper cross-section, it is to be rolled with a steam roller, weighing not less than 10 tons, until it is compacted to form a firm, smooth surface. The rolling is to begin at the sides, the shoulders for a width of at least 5 feet first being rolled until firm. When completed, the surface of the shoulders and of the second course of broken stone must be smooth and continuous with a cross slope as shown on the plans.

UNEVENNESS OR DEPRESSIONS.

"If any unevenness or depressions appear during or after the rolling of the second course, either on the surface of the shoulder or the broken stone, suitable material shall be added to remove all such unevenness or depressions, earth being used on the shoulders and stone for the macadam.

SPREADING CHIPS.

"After the second course of stone has been rolled and completed as specified, the surface voids are to be filled with chips, free from dust, which shall be whipped into the surface from shovels, the quantity being such as will just fill these surface voids. After the chips have been whipped into the surface, it shall be gone over with a stiff brush broom and all chips remaining on the surface of the stone swept into the voids in the surface, and if an excess remains after the voids have been filled, they shall be swept off to the edge of the macadam.

SPREADING BITUMINOUS BINDER.

"Upon the surface prepared as above described, there shall be uniformly distributed 1 gallon per square yard of surface of the asphalt binder herein specified. The asphalt binder shall be applied at a temperature not less than 350° F., and shall be spread on the surface in a manner which will insure that a uniform amount is applied to all parts of it.

ROLLING BINDER.

"Immediately after the first course of binder is spread, the surface is to be rolled, preferably with a tandem

roller, weighing not less than 8 tons. The roller must be provided with means to keep the surface of the wheels sprinkled with water. The rolling is to continue until the surface has become hard, smooth and as closely compacted as possible.

SPREADING SECOND COURSE OF CHIPS.

"After the first course of binder has been spread and rolled as above specified, there shall be spread a quantity of chips which will be just sufficient to fill the remaining voids in the surface. The chips shall be brushed into the voids with a stift brush broom.

SPREADING PAINT COAT OF ASPHALT BINDER.

"After the second course of chips has been spread and brushed into the surface, a second course of the approved binder shall be spread at the rate of ½ gallon per square yard. The binder shall be spread at a temperature of not less than 350° F. and shall be applied in such a manner as will insure that a thin even coat of the binder covers the entire surface.

DUSTING AND ROLLING FINISHED SURFACE.

"After the paint coat of the bituminous compound has been spread, the surface shall be dusted lightly with coarse quartz sand, not to exceed one (1) cubic yard per 300 square yards of surface, and the surface rolled with a 10-ton roller, the wheels being wet to prevent sticking. After the surface has been rolled, it shall be allowed to stand for one-half day before being opened to traffic."

The method recommended by the Association for Standardizing Paving Specifications is shown by the following extract from proposed specifications:

"Upon the bottom course shall be evenly spread crusher run stone which shall pass a 3-inch ring and be retained upon a 1-inch screen, to a finished depth of two and one-half (2½) inches. This course shall be dry rolled with a steam roller herein before mentioned only until the individual fragments have keyed together, the surface, while even and conforming to the required crown, being left open or porous in order to allow the penetration of the hot bituminous binder.

"The binder shall be heated in an approved heater equipped with a fixed or portable thermometer which will clearly and accurately indicate the temperature of the binder. The bituminous binder shall be heated to a temperature of not less than 250° F., nor more than 350° F., and shall be uniformly distributed over the macadam by suitable appliances at a rate of not less than one and seven-tenths (1.7) gallons to the square yard. Directly after application, clean trap rock, or equally satisfactory stone chips, free from dust and consisting of fragments which will pass a 1-inch ring but be retained upon a three-eighths (⅜) inch screen, shall be spread over the surface in sufficient quantities to fill the surface voids and prevent the binder from sticking to the wheels of the roller. Care shall be exercised not to apply more stone chips than will just fill the interstices and any surplus material shall be swept from the surface, as directed. The road shall then be rolled until solid, more stone chips or screenings being applied as required in order to maintain satisfactory conditions.

"A seal, flush, paint or squeegee coat of the hot binder shall be uniformly distributed over the surface at

a rate of at least one-half ($\frac{1}{2}$) gallon to the square yard. Clean stone chips or screenings such as previously described shall then be spread over this seal coat in just sufficient quantity to take up all excess of binder and form a smooth well-bonded surface when rolled. The road shall be rolled until smooth and firm and to the proper lines and grades.

"The stone must be dry and free from dirt or dust at the time of applying the bituminous binder. The application of binder shall not be made when the atmospheric temperature is below 50° F. unless specially permitted by the engineer."

Art. 51. Mixing Method.

The construction of bituminous macadam by the mixing method differs from that by the penetration method, in that the bitumen is mixed with the aggregate before it is placed upon the road. The lower course is formed in the usual manner, and finished as in water-bound macadam. The hot bitumen is mixed with broken stone, which is also usually heated, thus permitting the use of bitumen of harder consistency than could be used for pouring or for mixing with cold stone. The quantity of bitumen used is commonly somewhat less than with the penetration method, and should be sufficient to thoroughly coat all the stones of the aggregate.

It is desirable that the stone be so graded as to reduce the voids to a minimum, and sometimes different sizes of rock are mixed for this reason. Usually, however, in macadam work, careful grading of sizes would be too expensive, and the material is used between certain limits of size as it comes from the crusher, as in the other methods. In the construction of city pavements by the Bitulithic process, careful grading of stone into several sizes, and

exact mixing to secure best results, is practiced. This will be considered in Art. 73.

In constructing roads by this method, the mixing is done either in mechanical mixers or by hand. On large work, mechanical mixing is usually cheaper and more satisfactory. A number of portable mixers are now on the market, several of which are capable of doing excellent work. In hand mixing, the cost depends upon whether the plant is arranged for convenient handling of the materials, with the least amount of labor. The stone, in hand mixing, is commonly used cold, or it may be heated sufficiently to prevent the sudden chilling of the bitumen when it comes in contact with the stone. The bitumen employed should be a heavy viscous material, sufficiently soft to flow slightly at the temperature of the stone.

When the mixing of the bitumen and stone is completed, the concrete is placed upon the road to the desired thickness and rolled. Sometimes a layer of stone chips is added before rolling to prevent sticking. A paint coat is then usually applied to the surface, and covered with a light coating of screenings, and the whole rolled to a finished surface.

Bituminous macadam, constructed by the mixing method, has been extensively used in England, where it seems to be commonly preferred to the penetration, or tar grouting, method. The material used in England is almost exclusively tar. In many instances, tar concrete is prepared at a central plant, located conveniently to the supply of aggregate, and shipped ready for use to the site of the work. A complete discussion of English practice in the construction of tar macadam roads is given by Mr. J. Walker Smith.*

* Dustless Roads, Tar Macadam, London, 1909.

ART. 52. SELECTION OF BITUMINOUS MATERIALS.

The selection of bitumens for use on macadam roads always depend largely upon local conditions. The kinds of material which are most readily available; the character of the road metal to be employed and method of construction to be adopted; the local conditions of climate and traffic which the road is to meet, are all to be considered before a proper selection can be made.

The varying results which have been obtained with the same materials in different localities, and under differing conditions, make it impracticable, at present, to establish any standard specifications for such materials. Experience in the use of these materials is, however, rapidly shaping practice, and determining the most suitable materials for localities in which bituminous macadam construction is being used.

The Illinois Highway Commission uses the penetration method in constructing bituminous macadam, applying the bituminous binder at a temperature of about 350° F. The bitumens used are petroleum residuums, or oil asphalts, and the 1911 specifications are as follows:

ASPHALT BINDER.

" The asphalt binder used shall conform to the following specifications. The various properties herein described to be determined by the methods proposed by the American Society for Testing Materials.

"*Specific Gravity.* The asphalt shall have a specific gravity not less than 0.97.

"*Total Bitumen.* The asphalt shall be soluble in cold carbon bisulphide to the extent of at least 98 per cent.

"*Naphtha Insoluble Bitumen.* Of the total bitumen not

less than 20 per cent nor more than 25 per cent shall be insoluble in 86° Bé. naphtha.

"*Loss on Evaporation.* When 20 grams (in a tin dish 2½ inches in diameter, with vertical sides) are maintained at a temperature of 170° C. for 5 hours in a N. Y. testing laboratory oven, the evaporation loss shall not exceed 2 per cent and the penetration shall not have been decreased more than 25 per cent.

"*Fixed Carbon.* The fixed carbon shall not exceed 12 per cent by weight.

"*Penetration.* The penetration as determined with the Dow machine using a No. 2 needle, 100-gram weight, 5 sec. time and a temperature of 25° C., shall not be less than 5.0 mm. nor more than 10.0 mm.

"*Paraffine.* The asphalt shall not contain to exceed 2 per cent by weight of paraffine."

In the construction of bituminous macadam by the penetration method in Ohio, by Mr. James R. Marker, State Highway Commissioner, the bitumen is applied at temperature between 250° F. and 350° F. Several kinds of bitumen may be employed, each of which is provided for in the specifications, which are as follows:

OIL ASPHALT.

"1. The oil asphalt shall have a specific gravity of not less than c 965 at 25° C.

"2. It shall be soluble in c.p. carbon disulphide at air temperature to at least 99.5 per cent and shall contain not over 0.3 per cent organic matter insoluble.

"3. It shall contain not less than 18 per cent nor more than 25 per cent of bitumen insoluble in 86° Bé. paraffine naphtha at air temperature.

"4. When tested for 5 seconds at 25° C. with a standard

No. 2 needle weighted with 100 grams, it shall show a penetration of not less than 10 mm. nor greater than 20 mm.

" 5. When 20 grams of the material is heated for 5 hours in a cylindrical dish approximately 2½ inches in diameter by ¾ inch high, at a constant temperature of 163° C., the loss in weight by volatilization shall not exceed 3 per cent. The residue remaining shall show a penetration of not less than 6 mm. when tested in the manner hereinbefore described.

" 6. Its fixed carbon shall be not less than 7.5 per cent.

" 7. The oil asphalt upon delivery shall be free from water.

FLUXED NATIVE ASPHALT.

" 1. The fluxed asphalt shall have a specific gravity of not less than 1.01 at a temperature of 25° C.

" 2. Its solubility at air temperature in c.p. carbon disulphide for the following named materials, or materials similar thereto, shall be at least 95 per cent for Bermudez products, 81 per cent for Cuban products and 66 per cent for Trinidad products.

3. It shall contain not less than 18 per cent nor more than 25 per cent of bitumen, insoluble in 86° Bé. paraffine naphtha.

" 4. It shall yield not less than 9 per cent nor more than 13 per cent of fixed carbon.

" 5. The penetration shall be between 10 and 20 mm. when tested for 5 seconds at 25° C. with a No. 2 needle weighted with 100 grams.

" 6. When 20 grams of the material is heated for 5 hours in a cylindrical dish approximately 2½ inches in diameter by ¾ inch high at a constant temperature of 163° C., the loss in weight shall not exceed 5 per cent.

The residue thus obtained shall show a penetration of not more than 12 mm., nor less than 5 mm. when tested in the manner hereinbefore described.

"7. The fluxed asphalt upon delivery shall be free from water.

REFINED COAL TAR.

"1. The tar shall have a specific gravity of not less than 1.170 nor greater than 1.250 at 25° C.

"2. On extraction with carbon disulphide, it shall contain not more than 20 per cent free carbon.

"3. Upon ignition it shall show not over 0.5 per cent inorganic residue.

"4. When the sample of tar is submitted to the float test,* as hereinafter described, the float shall sink in water maintained at 50° C. in not less than 2½ minutes nor more than 3 minutes.

"5. When 250 c.c. of the tar is distilled in a 750-c.c. glass retort at a rate not exceeding 2 drops of distillate per second, the total distillate to 170°, as registered by a thermometer whose bulb is level with the bottom of the outlet of the body of the retort, shall not exceed 2 per cent by volume of the original material. The total distillate to 270° C. shall in no case exceed 50 per cent and when the tar contains more than 10 per cent free carbon, this distillate shall not exceed 40 per cent by volume of the original material.

"6. The tar upon delivery shall be free from water.

REFINED WATER-GAS TAR.

"1. The tar shall have a specific gravity of not less than 1.160 nor more than 1.185 at 25° C.

"2. It shall be soluble in c.p. carbon disulphide at air temperature to at least 95 per cent.

* See footnote on p. 208.

"3. Upon ignition it shall show not over 0.5 per cent inorganic residue.

"4. When the sample of tar is subjected to the float test,* as hereinafter described, the float shall sink in water maintained at 32° C. in not less than 13 minutes nor more than 18 minutes.

"5. When 250 c.c. of the tar is distilled in a 750 c.c. glass retort at a rate not exceeding 2 drops of distillate per second, the total distillate to 170° C., as registered by a thermometer whose bulb is level with the bottom of the outlet of the body of the retort, shall not exceed 4 per cent by volume of the original material. The total distillate to 270° C. shall not exceed 35 per cent by volume of the original material.

"6. The tar upon delivery shall be free from water."

* The apparatus used in making the float test is manufactured by Howard & Morse, Brooklyn, N. Y., and consists of two parts, an aluminum float or saucer, and a conical brass collar. The float contains an aperture in the bottom threaded so as to receive the smaller end of the brass collar. In using this apparatus, the collar is placed upon a brass plate having an amalgamated surface. The collar is then filled with the bitumen, after it has been softened by gentle heating. As soon as the bitumen has cooled sufficiently to handle, it is placed in ice-water for fifteen minutes. It must then be attached to the float, which should be immediately placed upon the surface of the water, which is maintained at 50° C. for the coal-tar test, and at 32° C. for the water-gas tar test. As the plug of bitumen in the brass collar becomes warm and fluid, it is gradually forced out of the collar and the water gains entrance to the saucer. The time in seconds elapsing between placing the apparatus on the water and when the water gains entrance into the saucer should be determined by means of a stop-watch.

CHAPTER VII.

FOUNDATIONS FOR PAVEMENTS.

ART. 53. PREPARATION OF ROAD-BED.

IN forming a road-bed upon which to place a pavement, the earth should be brought at subgrade to the form of a finished road-surface, leaving room for the superstructure of uniform thickness to be placed upon it. Thorough drainage must of course be carefully attended to when necessary. This has been already discussed in Chapter II.

In the construction of a road-bed to support a pavement, the same principles are involved as in the earthwork of a common road, which has been discussed in Art. 26, and the same methods may be employed in handling the earth. In grading, the surface should be left high enough to allow for the compression produced in rolling. The amount of settling to be expected under the roller will vary with the character of the material and the weight of the roller. With a heavy steam roller, the compression may vary from ½ inch for stiff soil in dry condition to about 3 inches for light porous soil. The allowance to be made can only be judged from experience with the soil in question.

The road-bed, after being brought to the proper grade, should be thoroughly compacted by rolling before placing the pavement. Sometimes in the use of a heavy roller, when the material is of a light nature, it is shoved forward in a wave before the roller and re-

fuses to become compacted, in which case a thin layer of gravel or small stone placed upon the surface of earth before rolling may have the effect of consolidating the road-bed under the roller to a hard surface.

The roller should pass several times over the road-bed. When low places are developed, which roll down below grade, they should be filled and rolled again until brought to proper grade. Passing the roller transversely over recently filled trenches will always produce depressions which require refilling. Where such trenches exist, the rolling should be very carefully done.

In rolling, soft spots are sometimes discovered, which cannot be compacted by rolling. In such cases the soft material should be removed and replaced with better material to a sufficient depth to admit of rolling the road-bed to a compact surface.

In some instances, repeated rolling of light material with a heavy roller may have the effect of working the material loose so that it moves in a wave before the roller, although the first rolling leaves the road-bed compact. In such cases it is desirable to avoid too much rolling.

Where much grading is to be done, it is usually desirable to do the rough work before setting the curb upon the street, if a new curb is to be placed. It is, however, much easier to finish the grade after the curb is set, as a line across the street at the top of the curb is a convenient means of getting the elevation of points on the subgrade.

ART. 54. TRENCHES IN STREETS.

The opening of trenches for water, gas, and sewer pipes in the streets is perhaps the greatest cause of de-

struction of pavements to be found in the average city. This is especially true of the smaller cities, where wear from traffic is not excessive.

In constructing a pavement in an unpaved street an effort should always be made to lay all pipes which are likely to be needed in the street for a considerable period, in so far as they can be foreseen, before placing the pavement. Where a cut is made through a pavement for a trench it is a matter of considerable difficulty to backfill the trench and replace the pavement in as good condition as before it was cut, and great care is required to prevent the subsequent settlement of the pavement over the trench. The filling of trenches over which a pavement is to be placed requires very close inspection, and frequently, neglect of such inspection causes much trouble subsequently.

The most common method of filling trenches in unpaved streets is to throw the earth in loosely, and pile the surplus earth in a ridge over the trench, leaving it for the natural settlement, when wet weather comes, to ultimately compact the earth in the trench. Usually, the settlement of such a trench will extend over a long period, and there is danger of injury to a pavement built over the trench, even after several months have elapsed and settlement seems to have taken place. Rolling will compact the earth in the top of the trench, but its effect does not reach to any considerable depth in the trench, or prevent later settlement. There are many instances in which disastrous settlements of pavements have occurred over trenches, although the material in the trenches had been considerably settled by rains and the surface rolled with a heavy roller.

Flooding. It is common practice to settle the earth in trenches by flooding with water. This is accomplished either by repeatedly filling a few inches of earth into the trench and then saturating with water, or by flooding the trench with a few inches of water and filling the earth into the water. It is difficult to compact the earth by flooding so that no further settlement will take place, and it is necessary to use care that the earth be not thrown in in too large quantities at once, as when the trench is filled with scrapers or graders. When the soil is clay, subsequent settlement will take place as the clay shrinks upon drying out.

In filling sewer trenches in this manner there is usually danger of breaking the joints of the sewer in flooding the trench. Several instances have been noted in which this has occurred, and the practice should be avoided.

Tamping. The only method of effectively compacting ordinary earth in a trench so that no danger of subsequent settlement shall exist is by placing the earth in thin layers, not more than 4 or 5 inches thick, and tamping each layer thoroughly. To accomplish this the earth must be damp enough to pack well, but not too wet.

The earth compacts into smaller space when rammed in the trench than it formerly occupied, so that when the pipe is small as compared with the size of the trench there may not be enough earth removed in excavating the trench to entirely refill it.

Art. 55. Purpose of Foundation.

The chief object of the foundation or base of a pavement is to distribute the concentrated loads which

come upon the surface of the road over a greater area of the usually softer and weaker road-bed, in order that these loads may not produce indentations in the surface.

In a foundation composed of independent blocks extending through its thickness, as in the case of a stone-block pavement in which the blocks rest directly upon the road-bed or upon a thin layer of sand, the load which comes upon the top of any block will be distributed over the area covered by the base of the block.

Where the foundation is composed of small independent particles, like sand or loose rounded gravel, with no cohesion through the mass, the pressure is distributed over the base of a cone whose vertex is in the point of application of the load, and the inclination of whose elements depends upon the friction of the particles of the material upon each other. In this case the area over which the load is distributed varies directly as the square of the thickness of the foundation. Sand, it is to be observed, has also the property, when confined as in a foundation, on account of its incompressible nature, of adjusting itself to a uniform pressure and resisting the deformation of the road-bed. If the small pieces composing the foundation are cemented together, or held as in masses of angular fragments by the interlocking of the angles, the foundation may act more or less as a whole, causing a distribution of the load over a considerable area, the extent of which will depend upon the resistance of the mass to bending.

The bases most commonly employed for pavements are sand, broken stone, and concrete. Foundations of brick and wood are also sometimes employed for pavements of the same materials.

ART. 56. BASES OF GRAVEL AND BROKEN STONE.

For light service on a good road-bed a satisfactory foundation may frequently be constructed of gravel or broken stone at much less expense than would be required for a concrete base. A foundation of this character should be constructed in about the same manner as a broken-stone road, the material being spread over the road-bed and thoroughly rolled to the required form. The stone or gravel employed should contain sufficient small material to fill the voids in the aggregate, or a binding material may be added to aid in compacting the foundation, and to close the interstices so as to prevent any settling of the material which is used to support the paving surface.

These foundations are sometimes used under brick pavements of light traffic with good results. It is important, in the construction of brick pavements in this manner, that the interstices in the base be thoroughly filled, as otherwise the sand cushion under the bricks may gradually settle into the foundation.

A foundation of this kind can never have the strength and permanence of a concrete base, and, while they may give good results when well constructed under proper conditions, they have frequently been used where a small additional expense for concrete would have been much more economical in the end.

ART. 57. CONCRETE BASES.

The best base for general use under pavements is without doubt that formed of hydraulic cement concrete. A bed of concrete made of good hydraulic

cement, well rammed and allowed to set and harden, becomes a practically monolithic structure, nearly impervious to water and possessing a high degree of strength against crushing.

The concrete is formed of a mixture of cement, sand, and broken stone or gravel. The proportions vary for different work and with the character of the materials. With good Portland cement the most common proportions for ordinary work are about one part cement, 3 parts sand, and 5 to 7 parts broken stone. With the various natural cements the proportions vary somewhat, but are usually about 1 part cement, 2 parts sand, and 4 or 5 parts of stone or gravel.

Natural cement is often employed for this purpose as being cheaper and possessing ample strength for the work, and concrete of the ordinary proportions with natural cement is to be preferred to that made with meager proportions of Portland cement giving about the same strength and cost. Proper tests should always be imposed for the purpose of securing good cement.*

Sand for use in mortar should be as clean and as free from loam, mud, or organic matter as possible. In general the presence of any foreign matter is to be avoided. Coarse sand is usually preferable to that which is very fine, provided it be fine enough to give a smooth mortar, as it affords better strength. The use of a mixture of grains of various sizes is usually desirable as giving less voids to be filled by the cement.

The aggregate used for concrete should be as hard

* For discussion of tests of cement see "Hydraulic Cement, its Properties, Testing and Use," by F. P. Spalding. John Wiley and Sons, New York.

and durable as possible, and that of angular form is preferable to rounded. The materials should be uniform in quality. When gravel is used which varies in quality, it should be blended by mixing in order to obtain uniform strength in the concrete. The best concrete will usually be made from the stone containing the smallest percentage of voids, provided the material be uniform. In a mass of ordinary broken stone the voids are usually from 40 per cent to 55 per cent of the volume. This may be considerably reduced by careful adjustment of the sizes. The broken stone is commonly limited in size to 2 or 2½ inches, and the whole output of the crusher is used, with the dust screened out. The quantity of sand needed is such as will fill the voids in the aggregate.

In preparing the concrete, the cement and sand should first be thoroughly mixed while dry, then the proper quantity of water be added all at once, and the mortar be vigorously worked with hoe or shovel for 2 or 3 minutes, until it comes to a smooth and uniform condition.

The quantity of water should be such as under energetic working will reduce the mortar to a soft, plastic condition, and should be determined by measure. The application of the water from a hose during the mixing is objectionable on account of the difficulty of regulating the quantity to produce mortar of proper consistency.

When the mixing of the mortar is complete, the stone or gravel may be added, and the whole mass turned several times with shovels until the mortar is evenly distributed through the aggregate. The stone should be wet by sprinkling before it is mixed with the mortar, in order to clean the surfaces of dust and

to prevent the absorption of water from the mortar before it sets.

The concrete, when ready, is placed in position and tamped to surface. For this use it is preferable that the concrete be of jelly-like consistency, such that it will quake under light ramming. The rammer commonly employed consists of a block of wood, or of cast iron, 6 to 8 inches square, flat on the bottom, and weighing 20 to 30 pounds. The tamping should cause the mortar to flush to the surface.

After completion the foundation should be allowed to stand several days before the pavement is placed upon it,— 3 to 6 days are usually required,— in order that the mortar may become entirely set. During setting the concrete should be protected from the drying action of the sun and wind, and should be kept damp to prevent the formation of drying cracks.

The quantity of material necessary to make a cubic yard of concrete varies with the density of the broken stone. For materials measured loose, to make a cubic yard of 1, 2, 4 concrete will require $1\frac{1}{4}$ to $1\frac{1}{2}$ barrels of natural cement, $\frac{4}{10}$ to $\frac{5}{10}$ cubic yard of sand, and $\frac{8}{10}$ to 1 cubic yard of broken stone. To make 1 cubic yard of 1, 3, 6 concrete requires $\frac{8}{10}$ to 1 barrel of Portland cement, $\frac{4}{10}$ to $\frac{5}{10}$ cubic yard of sand, and $\frac{8}{10}$ to 1 cubic yard of broken stone.

ART. 58. BITUMINOUS FOUNDATIONS.

Foundations of bituminous concrete are frequently used under asphalt and bitulithic pavements, and, in some instances, under other surfaces. These foundations are constructed in much the same way as bituminous macadam roads (see Chap. VI). In some

instances the bases are formed of concrete composed of broken stone and tar, or asphalt cement mixed in the same manner as the binder course for an asphalt pavement (see Art. 70), and rolling or tamping the concrete into place.

The more common method of construction is by spreading and rolling the broken stone, 4 or 6 inches thick, as for a macadam road, and covering the surface with a coating of bituminous cement. Coal-tar cement is ordinarily used for this purpose, or a mixture of coal-tar and asphalt.

The bituminous foundation is commonly employed in the construction of bitulithic pavements (see Art. 73). The advantage claimed for it is that it permits the overlying courses to bind into the foundation and holds the surface layer in place. Foundations of this kind give good results when the road-bed is firm, so that it may be rolled solid and is not likely to become unstable. It has not, however, the stability of hydraulic cement concrete and should not be used where strength is needed or where the road-bed is composed of spongy clay or other material which cannot be rolled to provide a solid sub-foundation.

ART. 59 MISCELLANEOUS FOUNDATIONS.

Brick Foundations. Foundations of brick have frequently been used under brick pavements. The pavement in such cases consists of two layers of brick, with sand between, and is known as *double-layer pavement.* These foundations are usually formed by placing upon the road-bed a layer of sand or gravel 3 or 4 inches thick, which is rolled thoroughly to a uniform surface, and then receives a layer of brick, commonly laid flat and

with the greatest dimension lengthwise of the street. These bricks are laid as closely as possible with broken joints. The joints are filled with sand carefully swept in, and the bricks are rammed to a firm bearing.

Upon this course of brick is placed a cushion layer of sand, and then the surface layer. The bricks of the lower layer may be of a cheaper grade than the surface paving brick, as they are not required to resist the attrition of travel.

Care must be used to thoroughly fill the joints in the foundation layer of brick in order that the sand in the cushion layer may not work downward and allow the surface bricks to settle.

These foundations were formerly quite extensively used for brick pavements, but have for the most part been superseded by concrete or macadam bases. They have, in many instances, given good results in use when resting upon a firm road bed, but lack the strength of the concrete foundation and are not usually economical.

Sand and Plank Foundation. Under many wood pavements, and sometimes under brick surfaces, foundations formed of sand and planks have been used. These foundations differ somewhat in construction in various localities, but are essentially a bed of sand or gravel, upon which is placed a layer of tarred boards which support the surface layer.

It is common to use a layer of sand 3 or 4 inches thick, which is compacted by rolling; after which the boards are laid lengthwise of the street close together, so as to form a floor upon which the blocks may be set. With a brick surface a cushion coat of sand is used under the surface layer.

Sometimes two layers of one-inch tarred boards are employed, the lower being laid crosswise of the street and the upper lengthwise of it. In other cases the boards of a single thickness are nailed to scantling laid across the street and bedded in the sand. The boards must in all cases press evenly upon the layer of sand that covers the road-bed.

These foundations were used under the round block-wood pavement, at one time quite extensively. They are employed only where low cost of construction is necessary, and are not economical when a durable road-surface is to be constructed.

Sand Foundations. Brick pavements have frequently been constructed with only a cushion coat of sand upon the earth road-bed. In some instances, where the road-bed is firm and well drained, forming a natural foundation, this method of construction has been successful under light traffic, but the failures have been numerous, and it is only under exceptional circumstances that such construction will prove economical. The same method has been applied to wood-block and stone-block pavements, stone blocks being usually set in a bed of sand or gravel 4 to 8 inches deep.

ART. 60. CHOICE OF FOUNDATION.

It is always important that the foundation be sufficient. The yielding of the base of the pavement means its destruction.

If a firm and durable foundation be employed, the surface may be renewed when necessary or changed from one material to another without disturbing the base, but if the base be weak the surface will be destroyed.

The saving of expense should be at the top rather than at the bottom of a pavement.

The thickness required for the foundation of a pavement depends upon the nature of the soil upon which it is to rest, and upon the extent and weight of the travel to which it is to be subjected.

When the road-bed is of a retentive material and likely to become wet and soft, the foundation should possess sufficient strength not to be broken through at points where the supporting power of the road-bed may be destroyed by water. It must also be able to resist the action of frost upon the soil below. In such cases 8 or 9 inches of concrete may be necessary. Six inches of good concrete, however, constitute a foundation of considerable strength, and it is only under severe conditions, poor support and heavy traffic, that a greater depth is necessary.

Under light traffic with good conditions, a less depth may be sometimes used; 4 inches of concrete is frequently employed to save expense, although 6 is the more common depth. A depth of 4 or 6 inches of well compacted gravel or broken stone is also usually sufficient where the conditions are such as to admit of the use of a foundation of that character.

It may be here observed that no definite prescription for any pavement, either as to choice of foundation or as to methods of construction, can fit all cases. What is most successful in one case is quite inapplicable in another. The blind following of particular rules by those not conversant with the principles upon which they are based has been the cause of many failures. Judgment must always be used in weighing the local conditions of the problem in hand.

CHAPTER VIII.

BRICK PAVEMENTS.

ART. 61. PAVING-BRICK.

THE requisites for a good paving-brick are that it shall be hard, tough, and impervious, as well as capable of enduring against the disintegrating influences of the weather.

The bricks in most common use are made from fire-clay of an inferior quality, or from an indurated clay or shale of somewhat similar composition.

These clays consist essentially of silicate of alumina, with usually small percentages of lime, magnesia, iron, potash, soda, and sometimes other elements. The range of composition for clays in common use is approximately as follows:

	Per cent.
Silica	60 to 75
Alumina	10 to 25
Iron oxide	3 to 8
Lime	0 to 4
Magnesia	0 to 3
Potash	0.5 to 3
Soda	0 to 2

In a few cases the quantity of lime is greater, varying from 8 to 12 per cent.

When the clay is very nearly pure silicate of alumina, it is capable of withstanding a high degree of heat without fusing, and is known as fire-clay. As the per-

centages of other ingredients increase, it becomes more fusible. The lime, magnesia, potash, and soda act as fluxing agents, and the readiness with which the clay can be melted depends upon the relative quantities of refractory and fluxing materials that it may contain.

Silica in excess tends to make the brick weak and brittle, while too great quantity of alumina causes the brick to crack and warp in the shrinking which occurs during burning. The proper adjustment of the relations between these elements is necessary to good results.

The quantity of lime in the clay is an important matter, as the presence of lime in an uncombined state in the brick may be productive of disintegration when the brick is exposed to the weather. A large percentage of lime in a clay is therefore to be regarded with suspicion, although not necessarily as cause for condemnation, as its effect depends upon the state of combination of the various ingredients of the brick. Magnesia probably acts in much the same manner as lime. Potash and soda are considered desirable elements in quantities to properly flux the clay in burning.

The fineness of a clay is also a matter of importance, both because a fine clay will fuse at a lower temperature than a coarse one, and because fineness is necessary to the production of even and close grained brick, and therefore conduces to make them tough and impervious.

To produce a good paving-brick, a clay is required which will vitrify at a high heat. A very refractory clay will make a porous brick, while if it melts at too low a temperature it cannot be burned sufficiently to become hard and tough.

The methods of manufacturing paving-brick vary in

different localities according to the character of the material to be worked. They are quite similar to those in use for common brick, only more thoroughly executed.

The clay is commonly reduced to a fine powder, tempered with water and passed through a machine that molds the bricks, which are then dried and afterward burned. Repressed bricks are those which are compressed in a mold after coming from the brick machine and before drying.

The process of burning occupies usually from 10 to 15 days.

The heat is at first slowly applied to expel the water, then raised to a high temperature for several days, after which the bricks are very slowly cooled.

There is considerable difference of opinion among engineers and manufacturers as to the exact amount of burning necessary. It is usually stated that the brick should be burned to the point of vitrification, but not completely vitrified. The burning must be thoroughly done to produce a strong and impervious brick, but there is undoubtedly a point beyond which, for some brick, further burning causes brittleness. Very gradual cooling is also necessary in order to toughen the brick. Smoothness and uniformity of texture in a paving brick is an important consideration as affecting its resistance both to crushing and to abrasion. The broken surface of the brick should present a uniform appearance both in texture and in color.

All the bricks used in the same pavement should also be of the same degree of hardness and toughness in order that the pavement may wear evenly, and to this end careful inspection should always be given to the bricks proposed for use, and all of those which are

defective, soft from imperfect burning, brittle from overburning or quick cooling, cracked or distorted by unequal shrinkage, should be rejected. An examination of the color and size of the bricks may frequently be useful in determining for any particular material whether individual bricks have received the proper degree of burning, after the engineer has become familiar with the make of brick under examination. The amount of shrinkage in burning is often a quite reliable index of the degree of burning to which the material has been subjected, and specifying within somewhat narrow limits the variation in size of bricks to be used together may often conduce to greater uniformity in the material employed. Some makes of brick vary quite appreciably in size for small differences in extent of burning, and without materially affecting the value of the product, but it is desirable to sort them closely and use those of each size by themselves.

The mistake is frequently made of placing too high value upon the element of hardness, which when carried to an extreme is sometimes attained at the expense of toughness, the brick becoming brittle and easily shattered. The author (under his guaranty on a pavement) has, on one occasion, been obliged to replace a small number of hard bricks, which at the time of laying were supposed to be among the best of the lot, on account of their becoming shattered under traffic, while somewhat softer brick from the same kilns, the use of which was questioned by the inspector, proved quite satisfactory in the same work.

The sizes of paving-bricks vary considerably as made by different manufacturers, the most common sizes approximating to those of building brick, varying

from about $2\frac{1}{4}$ to $2\frac{5}{8}$ inches in width, 8 to $8\frac{1}{2}$ inches long, and 4 inches deep, about 56 to 63 bricks being required for a square yard of pavement. A few makers also produce a *brick*, of about the same size but only $3\frac{1}{2}$ inches deep. A larger size, usually about $3 \times 9 \times 4$ inches, and known as a *paving-block* to distinguish it from the smaller *brick*, is quite largely employed. These usually require from 43 to 47 blocks per square yard.

Larger blocks have been tried, but have not come into general use, while some manufacturers make smaller sizes, requiring 70 to 75 bricks to the square yard of pavement.

Opinions differ as to the best sizes for use in pavements, some engineers specifying the smaller *bricks*, others the larger *blocks*. A good pavement can be built of either if proper attention be given to selecting the material. The sizes preferred by the various manufacturers depend largely upon the character of the clay or shale with which they have to deal. With some materials the size is limited by the distortion of large blocks in burning, and the smaller bricks are preferable; with others, larger blocks may be made at less cost in proportion to area of pavement, and perhaps with better and smoother work resulting. There seems to be no necessity for any increase in the usual depth of 4 inches as is sometimes proposed, and it may be possible that the adoption of the depth, $3\frac{1}{2}$ inches, now frequently used may in many instances somewhat lessen the cost of the pavement without affecting its length of service.

Much difference of opinion has been developed among engineers as to the advisability of rounding the corners of the brick, some requiring that the blocks be

repressed with corners rounded to a radius of $\frac{1}{4}$ or $\frac{3}{8}$ of an inch, while others specify square-edge brick, and in some instances that they shall not be repressed. On the one hand, it is maintained that in service the sharp corners will soon be knocked off and worn down more roughly and unevenly than if originally rounded, while, on the other hand, it is claimed that if a rigid filler like Portland cement be used, the joint may be filled level with the surface of the brick, and be much less likely to chip out than if the joint be widened at the top so as to cause the filler to present a thin edge at the sides. Both contentions seem reasonable under certain conditions, and the method of construction and character of filler used will ordinarily determine the proper form for the brick.

The desirability of repressing the brick is also a much discussed question, it being argued by some that the repressing of the material forms a more dense and compact block and increases its probable wear in use, and by others that the pressure applied to the material after it comes from the brick-machine disturbs the structure and injures the fiber of the brick, often forming laminations which are elements of weakness. With some materials this last contention seems to have some basis in fact, but in other and probably most materials no such condition can be found on examination of the structure of the brick. The views of individual manufacturers upon the question seem to depend mainly upon the kind of material they have to work with, and it would be difficult from existing data to say that either method necessarily gives the best results. Possibly those materials which approach most nearly to actual vitrification and are subject to considerable shrinkage during the burning are but

little affected in final density by the compression of the block before burning. It should be observed in this connection that whatever may be the value of repressing as to its effect upon the quality of the brick and wear of the pavement, it undoubtedly has the effect with some kinds of brick of giving a smoother and better surface to the pavement by producing a more regular and uniformly shaped brick.

In order to give sufficient space between the bricks for the joint-filling, some manufacturers make repressed bricks with lugs on one side to hold them a given distance apart when laid in the pavement. The wisdom of this under ordinary circumstances seems doubtful, as small joint-space is usually desirable, and experience shows that bricks laid close, even if carefully driven up, will usually give plenty of space for filling. Spacing-lugs are seldom required in specifications, but engineers have sometimes required their use for work on steep grades with the idea of giving better foothold to horses than the thin joints would afford. There may be some advantage in this, and some pavements so constructed on grades of above eight per cent have given satisfactory results, the lugs usually projecting about half an inch from the face of the brick, but in the author's own experience he has been unable to notice any difference in the use of the pavement with or without the wide joints, all being laid with bevel-edge brick.

Repressed bricks and blocks are frequently made with a groove or two, extending lengthwise of the brick on each side and sometimes across the ends, for the purpose of keying the blocks together when filled with the joint-filler. This may be an aid to rigid construction, though not necessary to good work.

It is usually limited to the larger blocks, which frequently have thin lugs, as well as the grooves, and are known as groove- and lug-blocks. They are well calculated to give a very firm construction.

ART. 62. TESTS FOR PAVING-BRICK.

To determine the probable durability of brick designed for use in paving, mechanical tests may be applied which will show the relative rank of different samples in their most important characteristics. It is, however, a matter of considerable difficulty to set a standard to which the brick should be required to conform, or to determine, from the behavior of the bricks under test, the relative value of various samples which it may be desired to compare.

The tests ordinarily proposed or used for this purpose are those of crushing strength, transverse strength, abrasion and impact, absorption, and specific gravity. The relative importance of these tests and the weight which should be given to their results is a matter concerning which considerable difference of opinion has been developed amongst engineers, and practice varies considerably. The National Brick Manufacturers' Association have considered the matter, and in 1895 appointed a committee which in 1897 reported a set of rules for making the tests, with resolutions expressing their views as to the relative importance and reliability of each. These rules, which were somewhat modified in 1900, are very commonly followed and furnish a standard method of testing.

CRUSHING TEST.

The recommendations of the commission for conducting this test are as follows:

"I. The crushing test should be made on half-bricks, loaded edgewise, or as they are laid in the street. If the machine used is unable to crush a full half-brick, the area may be reduced by chipping off, keeping the form of the piece to be tested as nearly prismatic as possible. A machine of at least 100,000 pounds capacity should be used, and the specimen should not be reduced below 4 square inches of area in cross-section at right angles to direction of load.

"II. The upper and lower surfaces should preferably be ground to true and parallel planes. If this is not done, they should be bedded in plaster of Paris while in the testing-machine, which should be allowed to harden ten minutes under the weight of the crushing planes only before the load is applied.

"III. The load should be applied at a uniform rate of increase to the point of rupture.

"IV. Not less than an average obtained from 5 tests, on 5 different bricks, shall constitute a standard test."

The result of a compressive test of stone or brick depends very largely upon how it is made, and the results of tests are only properly comparable with others made in the same manner and with equal care. The use of plaster beds as suggested above, it is thought, conduces greatly to regularity of result in the work of different men, as it tends to reduce the effect of differences in the accuracy of dressing the surfaces of contact. The size of the test-piece is also important, the strength usually increasing as the size in-

creases. Small pieces, 1½- or 2-inch cubes, are often employed because of the large force necessary to crush a whole or half brick, although where machinery exists capable of doing it the larger tests entail much less work in preparing specimens and also yield much more satisfactory results. Where small specimens are used it is to be observed that the unit strength will not be the same as for larger ones, and must be judged by a different standard. In the preparation of specimens it is better, when possible, to saw than to break them by chipping, in order not to injure the block by the shock of the blows.

The commission in their discussion concluded that no connection has been shown between high strength and the qualities necessary for a good paving material, and adopted the following resolution:

"WHEREAS, From the experimental work done so far by this commission, or by others so far as is known to us, in the application of the cross-breaking and crushing tests to paving-bricks, it is not possible to show any close relationship between the qualities necessary for a good paving material and high structural strength as indicated by either of these tests,

"*Resolved,* That for this reason the commission recommends that these tests shall be considered as purely optional in the examination of paving material, and not necessary as a proof of excellence."

It is to be observed that the actual crushing strength of a brick is not a matter of special importance in so far as any danger of the crushing of the material in the pavement is concerned, as no stress can there come upon it under ordinary circumstances which would endanger even a very weak specimen from direct crushing. It is thought, however, that to some extent

the value of the brick is indicated by its resistance to crushing, coupled, of course, with a proper examination of its other necessary attributes. A brick which possesses a high crushing strength is not necessarily a good paving-brick, as it may at the same time be brittle or of such composition as to easily disintegrate under the action of the weather; but one that yields to a low crushing strength is usually weak in wearing qualities and not fit for the purpose. For this reason this test is commonly included in specifications prescribing tests, although it is recognized that the relative wearing qualities of various makes of brick cannot be graded by its results. A good paving-brick, in the form of a 2-inch cube, will usually show a resistance to crushing of not less than 10,000 pounds per square inch. Much higher values are sometimes used in specifications, but their advantage is at least doubtful.

TRANSVERSE TEST.

The transverse strength is tested by supporting the brick upon two knife-edges near its ends and bringing a load through a third knife-edge upon the middle of the brick. The test may be made upon any ordinary testing-machine by providing the necessary knife-edges, but, like the compression test, requires care in manipulation to get good results. It is specially important that the brick have a perfectly even bearing upon the supports before the application of the load, in order that it may not be subjected to a twist under the load. The method adopted by the commission for this test is as follows:

I. Support the brick on edge, or as laid in the pavement, on hardened steel knife-edges rounded

longitudinally to a radius of 12 inches and transversely to a radius of one-eighth inch, and bolted in position so as to secure a span of six inches.

II. Apply the load to the middle of the top face through a hardened steel knife-edge, straight longitudinally and rounded transversely to a radius of one-sixteenth inch.

III. Apply the load at a uniform rate of increase till fracture ensues.

IV. Compute the modulus of rupture by the formula

$$f = \frac{3}{2} \frac{wl}{bd^2},$$

in which f = modulus of rupture in pounds per square inch;
w = total breaking load in pounds;
l = length of span in inches = 6;
b = breadth of brick in inches;
d = depth of brick in inches.

V. Samples for test must be free from all visible irregularities of surface or deformities of shape, and their upper and lower faces must be practically parallel.

VI. Not less than 10 brick shall be broken and the average of all be taken for a standard test.

The commission included this test with the crushing test in the recommendation that the test was to be considered optional and "not necessary as a proof of excellence." This test is easier to conduct satisfactorily, and probably gives, in general, a more reliable indication of the value of the material than the crushing test. It calls into play the tensile as well as compressive strength of the brick. The interior structure is shown by the break, and an opportunity is

given to judge of the uniformity and homogeneous character of the material.

The fracture of a tough and homogeneous specimen under a transverse load should be a clean break through the middle of the brick, and a close observation of the breaks may frequently be of considerable assistance in forming an idea of these qualities, although they may not be directly represented by the load required to break the specimen. The shattering of the brick in breaking, or an irregular break extending from the point of application of the load to one of the points of support, usually indicates brittleness of the material.

The modulus of rupture of good paving-bricks commonly ranges between 2000 and 3000 pounds per square inch, sometimes reaching 3500 or even 4000 pounds. It is usually somewhat greater for brick laid flat than for brick on edge.

ABRASION TEST.

In the convention of 1897 the Brick Manufacturers' Association adopted a method for this test consisting in rattling a given charge of bricks in a cylinder rotating about its axis, which is horizontal, and depending for its result upon the impact and abrasion of the bricks upon each other. In 1900, however, after more fully considering the matter, the test was modified, and a smaller charge of bricks, with the addition of a charge of cast-iron shot, was recommended as more nearly representing the conditions of practice and giving results more in accord with experience.

The method finally recommended by the Association is as follows:

"*I. Dimensions of the Machine.* The standard machine shall be 28 inches in diameter and 20 inches in length, measured inside the rattling-chamber.

"Other machines may be used varying in diameter between 26 and 30 inches, and in length from 18 to 24 inches; but if this is done, a record of it must be attached to official report. Long rattlers may be cut up into sections of suitable length by the insertion of an iron diaphragm at the proper point.

"*II. Construction of the Machine.* The barrel shall be supported on trunnions at either end; in no case shall a shaft pass through the rattling-chamber. The cross-section of the barrel shall be a regular polygon having 14 sides. The heads and staves shall be composed of gray cast iron, not chilled or case-hardened. There shall be a space of one-fourth of an inch between the staves for the escape of dust and small pieces of waste. Other machines may be used having from 12 to 16 staves, with openings from one-eighth to three-eighths of an inch between staves; but if this is done, a record of it must be attached to the official report of the test.

"*III. Composition of the Charge.* All tests must be executed on charges containing but one make of brick or block at a time. The charge shall consist of 9 paving-blocks or 12 paving-bricks, together with 300 pounds of shot made of ordinary machinery cast iron. This shot shall be of two sizes, as described below, and the shot-charge shall be composed of one-fourth (75 pounds) of the larger size and three-fourths (225 pounds) of the smaller size.

"*IV. Size of the Shot.* The larger size shall weigh about 7½ pounds and be about 2½ inches square and 4½ inches long, with slightly rounded edges. The

smaller size shall be cubes of 1½ inches on a side, with rounded edges. The individual shot shall be replaced by new ones when they have lost one-tenth of their original weight.

"*V. Revolutions of the Charge.* The number of revolutions of a standard test shall be 1800, and the speed of rotation shall not fall below 28 nor exceed 30 per minute. The belt-power shall be sufficient to rotate the rattler at the same speed whether charged or empty.

"*VI. Condition of the Charge.* The bricks composing the charge shall be dry and clean and as nearly as may be possible in the condition in which they were drawn from the kiln.

"*VII. Calculation of the Result.* The loss shall be calculated in the per cents of the weight of the dry brick composing the charge, and no result shall be considered as official unless it is the average of two distinct and complete tests made on separate charges of brick."

The commission regard this as the most important test to be applied to paving-brick, and in fact it is the only one having their indorsement. It seems reasonable to suppose that this test gives more nearly than the others a determination of the value of the brick for use in a pavement.

It is quite true that the action to which the brick is subjected in a test of this character is different from the wear to which it is subjected when firmly held in the pavement, but the qualities necessary to resist wear in the two cases are very similar. We may form an idea of whether a material is suitable for the proposed use from such experiments, although no definite idea of the amount of wear that it will en-

dure can be obtained from them. It should also be pointed out that the method of estimating the loss of the brick, from abrasion tests made in this manner, as percentages of the total weight of brick, can, in the comparison of different bricks, only give correct results when the bricks compared are of the same size and shape. A brick with rounded edges evidently could not properly be compared with one with sharp edges by this method, and some engineers have divided the test into two periods for the purpose of separating the knocking off of the corners and preliminary rounding of the brick from the later abrasion upon the rounded surfaces which would be more nearly comparable for different specimens. If, in the test, the loss in the rattler during the first half-hour be separated from that during the second half-hour, the latter will be found to be much less affected by the form of the brick.

In comparing bricks of different sizes it should be noted that a small brick presents more surface for abrasion than a large one in proportion to its volume, and the results of such comparisons would be considerably modified in some instances if the results be stated in terms of exposed surface instead of percentage of volume. With square-edged brick during the early period of the test, when corners are being chipped off, the loss is probably more nearly proportional to length of edges than to surface or volume, which would be still more to the disadvantage of the small brick. Care is therefore necessary in drawing conclusions from such tests concerning the relative values of different materials that all the conditions which may affect such conclusions be fully understood.

New Abrasion Test. The abrasion test as above described, after being in use for a number of years, was found somewhat unsatisfactory, on account of the variation in results obtained in different laboratories, and the National Paving Brick Manufacturers' Association, in 1911, recommended the adoption of a new machine, together with specifications for its use. These recommendations are as follows:

THE RATTLER.

" The machine shall be of good mechanical construction, self-contained, and shall conform to the following details, of material and dimensions, and shall consist of barrel, frame and driving mechanism as herein described.

THE BARREL.

" The barrel of the machine shall be made up of the heads, headliners and staves.

" The heads shall be cast with trunnions in one piece. The trunnion bearings shall not be less than two and one-half ($2\frac{1}{2}$) inches in diameter or less than six (6) inches in length.

" The heads shall not be less than three-fourths ($\frac{3}{4}$) inch thick nor more than seven-eighths ($\frac{7}{8}$) inch. In outline they shall be a regular fourteen-sided (14) polygon inscribed in a circle twenty-eight and three-eighths ($23\frac{3}{8}$) inches in diameter. The heads shall be provided with flanges not less than three-fourths ($\frac{3}{4}$) inch thick and extending outward two and one-half ($2\frac{1}{2}$) inches from he inside face of head to afford a means of fastening the staves. The flanges shall be slotted on the outer edge, so as to provide for two (2) three-fourths ($\frac{3}{4}$) inch bolts at each end of each stave, said slots to be thirteen-sixteenths

($\frac{13}{16}$) inch wide and two and three-fourths ($2\frac{3}{4}$) inches center to center. Under each section of the flanges there shall be a brace three-eighths ($\frac{3}{8}$) inch thick and extending down the outside of the head not less than two (2) inches. Each slot shall be provided with recess for bolt head, which shall act to prevent the turning of the same. There shall be for each head a cast-iron headliner one (1) inch in thickness and conforming to the outline of the head, but inscribed in a circle twenty-eight and one-eighth ($28\frac{1}{8}$) inches in diameter. This liner or wear plate shall be fastened to the head by seven (7) five-eighths ($\frac{5}{8}$) inch cap screws, through the head from the outside. These wear plates, whenever they become worn down one-half ($\frac{1}{2}$) inch below their initial surface level, at any point of their surface, must be replaced with new. The metal of which these wear plates are to be composed shall be what is known as hard machinery iron, and must contain not less than one (1) per cent of combined carbon. The faces of the polygon must be smooth and give uniform bearing for the staves. To secure the desired uniform bearing the faces of the head may be ground or machined.

THE STAVES.

"The staves shall be made of six (6) inch medium steel structural channels twenty-seven and one-fourth ($27\frac{1}{4}$) inches long and weighing fifteen and five-tenths (15.5) pounds per lineal foot.

"The channels shall be drilled with holes thirteen-sixteenths ($\frac{13}{16}$) inch in diameter, two (2) in each end, for bolts to fasten same to head, the center line of the holes being one (1) inch from either end and one and three-eighths ($1\frac{3}{8}$) inches either way from the longitudinal center line.

"The spaces between the staves will be determined by the accuracy of the heads, but must not exceed five-sixteenths ($\frac{5}{16}$) inch. The interior or flat side of each channel must be protected by a lining or wear plate three-eighths ($\frac{3}{8}$) inch thick by five and one-half ($5\frac{1}{2}$) inches wide by nineteen and three-fourths ($19\frac{3}{4}$) inches long. The wear plate shall consist of medium steel plate, and shall be riveted to the channel by three (3) one-half ($\frac{1}{2}$) inch rivets, one of which shall be on the center line both ways and the other two on the longitudinal center line and spaced seven (7) inches from the center each way. The rivet holes shall be countersunk on the face of the wear plate and the rivets shall be driven hot and chipped off flush with the surface of the wear plate. These wear plates shall be inspected from time to time, and if found loose shall be at once reriveted, but no wear plate shall be replaced by a new one except as the whole set is changed. No set of wear plates shall be used for more than one hundred and fifty (150) tests under any circumstances. The record must show the date when each set of wear plates goes into service and the number of tests made upon each set.

"The staves when bolted to the head shall form a barrel twenty (20) inches long, inside measurement, between wear plates. The wear plates of the staves must be so placed as to drop between the wear plates of the heads. These staves shall be bolted tightly to the heads by four (4) three-fourths ($\frac{3}{4}$) inch bolts, and each bolt shall be provided with lock nuts, and shall be inspected at not less frequent intervals than every fifth (5th) test and all nuts kept tight. A record shall be made after each such inspection, showing in what condition the bolts were found.

THE FRAME AND DRIVING MECHANISM.

"The barrel shall be mounted on a cast-iron frame of sufficient strength and rigidity to support same without undue vibration. It should rest on a rigid foundation and be fastened to same by bolts at not less than four (4) points.

"It should be driven by gearing whose ratio of driver to driven should not be less than one (1) to four (4). The countershaft upon which the driving pinion is mounted should not be less than one and fifteen-sixteenths ($1\frac{15}{16}$) inches in diameter with bearings not less than six (6) inches in length and belt driven, and the pulley should not be less than eighten (18) inches in diameter and six and one-half ($6\frac{1}{2}$) inches in face. A belt of six (6) inch double-strength leather, properly adjusted, so as to avoid unnecessary slipping, should be used.

"The National Paving Brick Manufacturers' Association will furnish without charge to all proper applicants the complete drawings of a machine which will meet the above specifications and requirements.

THE ABRASIVE CHARGE.

"(a) The abrasive charge shall consist of two sizes of cast-iron spheres. The larger size shall be three and seventy-five hundredths (3.75) inches in diameter when new and shall weigh when new approximately seven and five-tenths (7.5) pounds (3.40 kilos) each. Ten shall be used.

"These shall be weighed separately after each ten (10) tests, and if the weight of any large shot falls to seven (7) pounds (3.175 kilos) it shall be discarded and a new one substituted; provided, however, that all of

the large shot shall not be discarded and substituted by new ones at any single time, and that so far as possible the large shots shall compose a graduated series in various stages of wear.

"The smaller size spheres shall be when new one and eight hundred seventy-five thousandths (1.875) inches in diameter and shall weigh not to exceed ninety-five hundredths (.95) pound (0.430 kilo) each. Of these spheres so many shall be used as will bring the collective weight of the large and small spheres most nearly to three hundred (300) pounds, provided that no small sphere shall be retained in use after it has been worn down so that it will pass a circular hole one and seventy-five hundredths (1.75) inches in diameter, drilled in a cast-iron plate one-fourth (¼) inch in thickness or weigh less than seventy-five-hundredths (.75) pound (or .34 kilo). Further the small spheres shall be tested by passing them over such an iron plate drilled with such holes, or shall be weighed after every ten (10) tests, and any which pass through or fall below specified weight, shall be replaced by new spheres, and provided, further, that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that so far as possible the small spheres shall compose a graduated series in various stages of wear. At any time that any sphere is found to be broken or defective it shall at once be replaced.

"(b) The iron composing these spheres shall have a chemical composition within the following limits:

Combined carbon—Not less than 2.50 per cent.
Graphitic carbon—Not more than 0.20 per cent.
Silicon—Not more than 1 per cent.
Manganese—Not more than 0.50 per cent.
Phosphorus—Not more than 0.25 per cent.
Sulphur—Not more than 0.08 per cent.

"For each new batch of spheres used the chemical analysis must be furnished by the maker, or be obtained by the user, before introduction into the charge, and unless the analysis meets the above specifications, the batch of spheres shall be rejected.

THE BRICK CHARGE

"The number of brick per charge shall be ten (10) for all bricks of the so-called 'block size' whose dimensions fall between from eight (8) to nine (9) inches in length, three (3) and three and three-fourths ($3\frac{3}{4}$) inches in breadth and three and three-fourths ($3\frac{3}{4}$) and four and one-fourth ($4\frac{1}{4}$) inches in thickness. No block should be selected for test that would be rejected by any other requirements of the specifications.

The brick shall be clean and dried for at least three (3) hours in a temperature of one hundred (100) degrees F. before testing.

THE TEST

"The rattler shall be rotated at a uniform rate of not less than twenty-nine and one-half ($29\frac{1}{2}$) nor more than thirty and one-half ($30\frac{1}{2}$) revolutions per minute, and eighteen hundred (1800) revolutions shall constitute the standard test.

"A counting machine shall be attached to the rattler for counting the revolutions.

"A margin of not to exceed ten (10) revolutions will be allowed for stopping.

STOPPING AND STARTING

"Only one (1) start and stop per test is regular and acceptable.

THE RESULTS

"The loss shall be calculated in percentage of the original weight of the dried brick composing the charge. In weighing the rattled brick any piece weighing less than one (1) pound shall be rejected.

RECORDS

"(*a*) The operator shall keep an official book, in which the alternate pages are perforated for removal. The record shall be kept in duplicate, by use of a carbon paper between the first and second sheets, and when all entries are made and calculations are completed the original record shall be removed and the carbon duplicate preserved in the book. All calculations must be made in the space left for that purpose in the record blank, and the actual figures must appear. The record must bear its serial number, and be filled out completely for each test, and all data as to dates of inspection and weighing of shot and replacement of worn-out parts must be carefully entered, so that the records remaining in the book constitute a continuous one. In event of further copies of a record being needed, they may be furnished on separate sheets, but in no case shall the original carbon copy be removed from the record book.

"(*b*) The blank form upon which the record of all official brick tests is to be kept and reported is as follows:

REPORT OF STANDARD RATTLER TEST OF PAVING BRICKS.

Identification Data.

Name of the firm furnishing sample..................Serial No. (   )
Name of the firm manufacturing sample.........................
Street or job which sample represents..............................
Brands or marks on the brick..
Quantity furnished.......................Drying treatment........
Date received..........................Date tested.............
Length................Breadth..................Thickness.....

Standardization Data.

Number of charges tested since last inspection.....................

Weight of Charge (After Standardization).	Condition of Locknuts on Staves.	Condition of Scales.
10 Large spheres....... Small spheres.......		
Total.........		

Number of charges tested since stave linings were renewed...........
Repairs (Note any repairs affecting the condition of the barrel).......

Running Data.

	Time Readings.			Revolution Counter Readings.	Running Notes. Stops, etc.
	Hours	Min.	Sec.		
Beginning of test Final reading ...					

Weights and Calculations.

Initial weight of 10 bricks.. Final weight of same......		Percentage loss (Note.—The calculation must appear)
Loss of weight...........		

Number of broken bricks and remarks on same.....................
I certify that the foregoing test was made under the specifications ....of.........................and is a true record.

(Signature of Tester)

....

Date......................Location of Laboratory

ABSORPTION TEST.

This test is made by weighing the specimen dry, then saturating it with water, weighing again, and stating the absorption as a percentage of the dry weight. The Commission of the Brick Manufacturers' Association oppose the use of this test, but recommend the following procedure for the test when used:

I. The number of bricks for a standard test shall be 5.

II. The test must be conducted on rattled bricks. If none such are available, the whole bricks must be broken in halves before treatment.

III. Dry the bricks for 48 hours at a temperature ranging from 230 degrees to 250 degrees F. before weighing for the initial dry weight.

IV. Soak for 48 hours, completely immersing the brick.

V. After soaking and before reweighing wipe the brick until free from surplus water and practically dry on the surface.

VI. Reweigh the samples at once on scales which are sensitive to 1 gram.

VII. The increase in weight due to absorption is to be calculated in percentage of the dry weight of the original bricks.

The commission also adopted the following resolution:

"*Resolved*, That, in the opinion of the commission, any paving-brick which will satisfy the requirements of reasonable mechanical tests will not absorb sufficient water to prove injurious to it in service. We therefore recommend that the absorption test be abandoned as unnecessary, if not actually misleading."

The purpose of this test, when made, is to insure the proper burning of the brick to a compact and non-absorbent structure. It is probable, as claimed by the commission, that these qualities will always be shown by the other tests, and that this one is not of very great importance, but in many instances it may give useful information. A good paving-brick will not usually absorb more than 4 per cent or 5 per cent of water, but the amount of absorption depends largely upon the nature of the material from which the brick is made. Many of the shale bricks absorb less than 1 per cent of water if properly burned, while some of the so-called fire-clay bricks when of equally good quality will absorb 3 per cent or 4 per cent. A specification which would insure the proper burning of the one class would exclude the best of the other class. A limit to the amount of absorption allowable is, however, commonly set in specifications.

The requirement of drying 48 hours is probably, in most instances, sufficient and reduces the moisture in the brick so that the further loss from continued drying would be very slight, but the saturation of the brick will not usually be accomplished by immersing for 48 hours. Some bricks will in that time have taken up but a small part of the water they would finally absorb, and much longer time would be necessary to give a complete indication in this particular. Some experiments by Mr. Harrington of St. Louis, the results of which were presented to the Brick Manufacturers' Association, showed a considerable change in the quantity of water absorbed by some bricks through a period of 24 weeks, and a considerable variation in the rate of absorption by different bricks.

The application of the test as proposed may serve to show whether the absorption is within the proper limits for a paving-brick, and when properly applied to particular makes of brick may indicate the degree of burning, although it is not of much value in the comparison of the qualities of different bricks where each shows results within reasonable limits.

SPECIFIC-GRAVITY TEST.

A test for specific gravity is sometimes included in specifications with a view to insuring the burning of the brick to the proper density.

In consequence, however, of the variation of bricks made from different materials it does not seem feasible to adopt any requirement foı general use which would be of much value, and as the same qualities are determined by other tests it seems unnecessary. The Commission of the Brick Manufacturers' Association recommend the abandonment of this test.

COMPARISON OF TESTS.

Specifications for brick pavements commonly require that the brick reach certain limiting values on some of the tests which have been described. The crushing test and the specific gravity test, while useful sometimes in a study of the character of materials, are of no value in specifications and are seldom used. Absorption is sometimes specified, a limit of 2 to 4 per cent being given for the shale brick, but is a doubtful value as a measure of quality. The transverse test is frequently used, requiring about 1800 to 2000 pounds per square inch as modulus of rupture by the standard test.

The main dependence, in specifications, is usually placed upon the rattler test, which is without doubt the most important, as showing more nearly than the others the qualities necessary in a brick to give good wear under traffic in a pavement, and many specifications now require no other test for acceptance of the brick. Specifications vary in the percentage of loss allowed, in testing by the old method, from about 18 to 27 per cent, according to brick available in the locality, the intensity of traffic, and the experience of the engineer with the test. In adopting the new test the American Society of Municipal Improvements recommend that the limit of loss of weight be fixed at 22 per cent for heavy, 26 per cent for medium, and 28 per cent for light traffic streets. The Association for Standardizing Paving Specifications recommends that the brick shall not lose more than 22 per cent of their weight, but provides that "where medium or light traffic or other conditions which in the opinion of the engineer do not require a brick sufficient to stand an abrasion loss of 22 per cent, brick of a quality sufficient to stand a loss of 25 per cent or even 28 per cent may be used."

Art. 63. Construction of Brick Pavements.

The work to be performed in laying a brick pavement, after grading and rolling the road bed (see Art. 53), consists in placing the foundation; forming a cushion coat of sand over the foundation; laying the bricks upon the sand cushion; rolling, or ramming, the bricks to a uniform surface and bearing; culling all broken and imperfect bricks; filling the joints between the bricks; cleaning the pavement and opening it to traffic.

Foundation. A brick pavement should have a firm

foundation. As the surface is made up of small independent blocks, each brick must be adequately supported from below, or the loads coming upon it may force it downward and cause unevenness. The wear of the pavement depends very largely upon the maintenance of a smooth even surface, as any unevenness will cause the bricks to chip on the edges, and also produce impact from the loads passing over the pavement.

The best foundation for a brick pavement is doubtless one of concrete, laid after the manner given in Art. 57. For light or moderately heavy traffic, such as that of the ordinary small city where the road-bed is of firm soil and properly drained, the concrete is usually placed 4 to 6 inches thick. If the traffic be very heavy or where from any cause the road-bed is not firm, it may be advisable to still farther increase the depth.

The double-layer pavement (see Fig. 24) consists of a foundation made by placing a layer of sand or gravel 3 to 5 inches thick upon the road-bed, rolling it thoroughly and laying a course of bricks upon it. The bricks are laid flat with their greatest dimension lengthwise of the street, as explained in Art. 59. This foundation has been extensively used under brick pavements, and has often given satisfactory results. It is now largely giving place to concrete in the better class of work, and in many cases under light traffic its economy is questionable, as the layer of gravel would often answer equally well without the lower layer of bricks. A modification of this base has been used in a few instances, in which the joints between the bricks are filled with Portland cement mortar. When such a base can be placed cheaper than concrete, it may give good service. The National Paving Brick Manufacturers' Association propose the following method of construction:

"Upon the sub-grade as heretofore prepared shall be spread a base of sand two (2) inches in thickness and which shall be brought to a perfect grade, conforming to that of the finished street.

"There shall be laid flatwise at right angles with the street, upon this grade thus prepared, a layer of No. 2 Paving Block not less than three (3) inches in thickness, the interstices of which shall be filled with a filler composed of two parts of clean sand and one part of Portland cement. This filler shall be prepared and applied as provided for in Section Ten of this direction and specification. The foundation thus made should remain undisturbed at least thirty-six (36) hours before the sand cushion herein provided for may be spread, and at least ten (10) days must elapse before rolling and compacting of brick surface is allowed, and in no event must teams be permitted or hauling be allowed upon this surface during this period."

Sand Cushion. The sand cushion consists usually of a layer of sand varying, in the practice of different engineers, from 1 to 2½ inches in thickness over the surface of the foundation. The most common practice is to make the sand cushion 2 inches thick. It should be deep enough to admit of the brick being driven to a smooth surface, and to take up any inequalities in the surface of the foundation and differences in thickness of brick. When a very thin cushion layer is employed it is necessary to secure much greater accuracy in forming the surface of the foundation, and it is much more difficult to uniformly bed the bricks than when the usual thickness is used. It has also been claimed that the thicker sand-bed has a marked tendency to diminish the rumbling of the pavement. This, however, is perhaps rather doubtful.

In forming the sand-bed the sand is spread over the foundation a little deeper than the bed is to be left, and is then drawn off to a smooth surface by the use of a form, cut to the desired shape of the surface, which extends across the street, and slides on the curbs or on stringers laid lengthwise of the street as may be convenient. The making of a good firm bed requires that considerable sand shall be pulled off from all parts of the bed, and the sand should always be two or three inches deep against the front of the form when drawing it to cut the bed. In order to accomplish this, without failing to cut a perfect surface through the form leaving the guides and riding up on the sand, considerable weight is required on the form when drawing it. In some cases the sand cushion is rolled with a light roller after being formed with a template. The specifications of the Association for Standardizing Paving Specifications require that this be done.

The sand for a cushion should be clean and free from pebbles, which prevent the formation of a smooth bed, and possibly also cause the breaking of the bricks in ramming the surface.

When the sand cushion is 1½ or 2 inches deep, an allowance of about half an inch is necessary for settlement in driving the bricks to surface.

Laying the Brick. The bricks in a street pavement are usually laid on edge in courses across the street, each alternate course being begun with a half-brick to break joints in the courses. This is illustrated in Fig. 23, which represents a pavement as constructed for heavy traffic on concrete foundation.

In many cases the gutter-bricks are turned with the greatest dimension lengthwise of the street, with the

object of facilitating the flow of surface-water in the gutter. The advantage of this is doubtful, as it

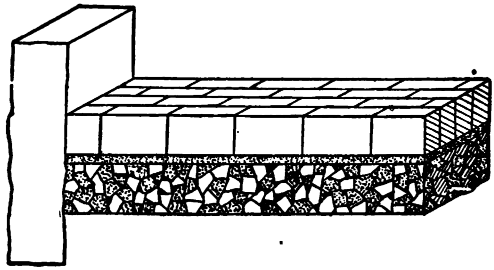

FIG. 23.

has the effect of breaking the bond of the pavement between the gutter-bricks and roadway. This is shown in Fig. 24, which represents the construction of a

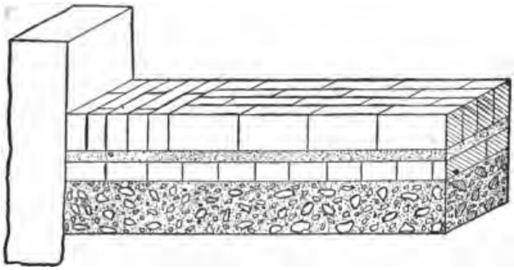

FIG. 24.

double-layer pavement with brick and gravel base, as has been commonly used under light or moderate traffic.

In laying the bricks the men stand on the pavement already laid and, beginning at a curb, lay three or four courses across the street at once, the bricks being wheeled and piled on the edge of the finished work

by laborers working continually in advance of the men laying. Wheeling over the newly laid bricks should be done on planks, to prevent driving the bricks out of surface. The courses may be kept straight and close together by driving back each block of eight or ten courses, a straight piece of plank four or five feet long being held by a handle on top against the side of the last course of bricks, and tapped lightly with a sledge.

Surfacing the Pavement. After the surface layer of bricks is in position it should be swept clean and rammed or rolled to a smooth and uniform surface. A five- or six-ton roller may be employed, passing three or four times over the surface, or a wooden rammer loaded with lead to a weight of 80 or 100 pounds may be used by striking upon a plank laid lengthwise of the street. The plank should be 10 or 12 feet long by about a foot wide and 3 inches thick, and used only so long as it retains its form and solidity.

The National Paving Brick Manufacturers' Association recommends the following procedure in compacting and smoothing the surface of the pavement:

"After the brick in the pavement are inspected and the surface is swept clean of spalls, they must be well rolled, with a steam roller weighing not less than three nor more than five tons, in the following manner: The brick next the curb should be tamped with a hand wood tamper to the proper gutter grade. The rolling will then commence near the curb at a very slow pace and continue back and forth until the center of the pavement is reached, then pass to the opposite curb and repeat in the same manner to the center of the street. After this first passage of the roller the pace may be quickened and the rolling continued until each brick is firmly imbedded in the sand cushion. *The roller shall then be*

started at the end of the block and the pavement rolled transversely at an angle of 45 *degrees to curb, repeat the rolling in like manner in the opposite direction.* Before this transverse rolling takes place all broken or injured brick must be taken up and replaced with perfect ones."

When the pavement has been brought to surface a careful inspection should be made and all defective or broken brick removed and replaced, a pair of brick-tongs being used for the purpose, and all low bricks or low spots being raised and brought to surface. A straight-edge is desirable in determining surface, as the appearance is often deceptive to the eye, and a slight variation in color of brick is frequently mistaken for an irregularity of surface. Sometimes the pavement is sprinkled and soft bricks picked out by observing whether they hold moisture; this method should be used with caution and with full knowledge of the material, as sometimes a comparatively slight absorption will show quite markedly.

ART. 64. FILLING THE JOINTS.

There is much difference of opinion amongst municipal engineers concerning the best material to use in filling the joints in a brick pavement. The materials commonly employed are sand, Portland-cement grout, and asphaltic or coal-tar paving-cement. Certain patent fillers of more or less the same character are also sometimes employed.

Sand Filler. In using sand as a filler, a thin layer of sand is spread over the pavement and raked or swept into the joints until they are thoroughly filled. In some instances the sand is artificially dried before putting it upon the bricks, but ordinarily, in mod-

erately dry weather, the sand may be spread in a thin layer on the bricks and allowed to dry before sweeping in. After the joints are well filled a light layer of sand is placed on top of the pavement and it is opened to traffic. The jarring of the traffic will cause the sand to settle more or less in the joints for a considerable time, and the sand cover should be retained for several weeks. The sand used for filling should be fine and sharp, free from loam and dirt. It must not pack or cake on top of the brick under traffic. In many instances sand has been used as a filler with satisfactory results and given good service even under moderately heavy traffic. It makes a practically impervious joint and holds the bricks quite firmly in place. It seems desirable in the use of sand filler to employ round-edge bricks, as the edges are not held so firmly as with a rigid filler, and if sharp are more likely to be chipped off, while the round edges aid in thoroughly filling the joints with the sand.

Portland-cement Filler. For filling joints with Portland cement a grout composed of equal parts of cement and sand is commonly employed. This grout is mixed in a tight box to a condition such that it will readily flow into the joints, and is swept in with brooms until the joints are thoroughly filled. The easiest method of securing the complete filling of the joint is probably that of applying the grout in two parts, mixing the first part very wet and filling the joints nearly full. As the grout begins to stiffen, the draining out of the water causes it to settle somewhat, but thoroughly fills and seals the lower part of the joint. The second part may then be mixed a little stiffer and the upper part of the joint be readily filled flush with the top of the bricks.

In handling the grout it is necessary that it be mixed quickly and applied at once without giving it time to settle, in order that it may retain its consistency and no separation of its materials take place. A pavement so filled becomes practically a monolithic mass, as the bricks are firmly held together and the joint is filled flush with the edges of the bricks with a material which soon becomes about as hard as the bricks themselves. The National Paving Brick Manufacturers' Association advocates the exclusive use of this filler, and recommends the following method of applying it:

"The filler shall be composed of one part each of clean, sharp sand and Portland cement. The sand should be dry. The mixture, not exceeding one-third bushel of the sand, together with a like amount of cement, shall be placed in the box and mixed dry, until the mass assumes an even and unbroken shade. Then water shall be added, forming a liquid mixture of the consistency of thin cream.

"The side and edges of the brick should be thoroughly wet before the filler is applied by being gently sprinkled.

"From the time the water is applied until the last drop is removed and floated into the joints of the brick pavement, the mixture must be kept in constant motion.

"The mixture shall be removed from the box to the street surface with a scoop shovel, all the while being stirred in the box as the same is being thus emptied. The box for this purpose shall be 4 feet 8 inches long, 30 inches wide and 14 inches deep, resting on legs of different lengths, so that the mixtures will readily flow to the lower corner of the box, the bottom of which should be 6 inches above the pavement. This mixture, from the moment it touches the brick shall be thoroughly swept into the joints.

"Two such boxes shall be provided in case the street is twenty feet or less in width; exceeding twenty feet in width, three boxes should be used. (See specifications for making same.)

"The work of filling should thus be carried forward in line until an advance of fifteen to twenty yards has been made, when the same force and appliances shall be turned back and cover the same space in like manner, *except* to make the proportions *two-thirds Portland cement* and *one-third sand*.

"To avoid the possibility of thickening at any point there should be a man with a sprinkling can, the head perforated with small holes, sprinkling gently the surface ahead of the sweepers.

"Within one-half to three-quarters of an hour after this last coat is applied and the grout between the joints has fully subsided and the initial set is taking place, the whole surface must be slightly sprinkled and all surplus mixture left on the tops of the brick swept into the joints, bringing them up flush and full.

"After the joints are thus filled flush with the top of the brick and sufficient time for hardening has elapsed, so that the coating of sand will not absorb any moisture from the cement mixture, one-half inch of sand shall be spread over the whole surface, and in case the work is subjected to a hot summer sun, an occasional sprinkling, sufficient to dampen the sand, should be followed for two or three days."

When using Portland cement filler, an expansion joint must be placed next the curb on each side of the street, to prevent the brick surface being lifted from the sand cushion by expansion. This joint is made by placing strips of wood along the curb, against which the brick may be set, and after the Portland cement filler has been

put in, the boards are removed and the expansion joints filled with asphaltic or coal tar cement.

Sometimes expansion joints are also used at intervals across the street to provide for longitudinal expansion. To be efficient, these joints should not be less than $\frac{3}{4}$ inch, when spaced 50 feet apart. They will usually be nearly closed in a few months, the paving pitch being forced out by the expansion. Such joints are not usually necessary on pavements of uniform gradients, but where changes occur in the rate of grade, and at intersections expansion must be carefully provided for. After completion, the pavement should stand at least a week or ten days before it is opened to traffic, to allow sufficient time for the cement to harden. During this time it should not be exposed to hot sun or permitted to dry out too much; commonly a light coating of sand is spread over it, and sometimes it is dampened by frequent sprinklings.

Bituminous Filler. The bituminous cements employed as fillers for brick pavements may be prepared from coal tar or petroleum residuums, or from natural asphalt, and are similar in character to the materials used for bituminous macadam or in the preparation of asphalt surface mixtures.

On account of the variation in the materials used, the results obtained with bituminous fillers have differed widely in different places. In many cases very satisfactory results have been obtained with these fillers; in others, the susceptibility to temperature changes has made them failures, the material melting and running out of the joints in hot weather, or becoming brittle and chipping out in cold weather.

Bituminous fillers, when of good materials and properly applied, give very satisfactory results. They have the

advantage over sand of being quite impervious to water, while they are not so rigid as Portland cement filler and are less noisy. These materials are under the disadvantage that well-defined specifications, which will insure the quality of the material, have not been worked out. Most of the tar fillers which have been on the market are too susceptible to changes of temperature. Some of the asphaltic fillers have given good results. For asphaltic fillers, the Association for Standardizing Paving Specifications recommends the following requirements:

"The interstices in the brick shall be completely filled with an asphalt filler heated to a temperature of not less than 350° F. nor more than 450° F. This asphalt filler shall not contain pitch nor any part of coal tar. It shall contain at least 92 per cent of bitumen soluble in carbon disulphide. It shall remain pliable at all temperatures to which it may be subjected as a street paving filler; it shall be absolutely proof against water and street liquids; it shall firmly adhere to the brick and be pliable rather than rigid. Care shall be exercised to completely fill all openings around street structures and the street shall not be used for traffic until the filler is completely set. A top dressing of sand shall be spread immediately after the filler is applied and while it is still soft."

"The penetration shall conform to the following:

"No. 2 needle	5 sec.	100 grams at	77 degrees F., 25 to 60.
"No. 2 needle	1 min.	200 grams at	32 degrees F., not below 25.
"No. 2 needle	5 sec.	50 grams at	115 degrees F., not below 110."

When bituminous filler is employed it is melted in kettles on the street and poured hot into the joints. The paving-cement is applied at a temperature of 300°

to 400° F., and should be applied only when the bricks are dry. After the joints are filled a light layer of sand is spread over the surface, and serves under the traffic to clean the surface from any surplus bitumen which may be smeared over it.

ART. 65. MAINTENANCE OF BRICK PAVEMENTS.

The maintenance necessary for a brick pavement consists in keeping it clean and carefully watching it, especially during the first year or two years, to see that no breaks occur due to the use of defective bricks in the surface or to insufficient support from the foundation at any point. When any unevenness from either of these causes appears, it should be at once rectified before the pavement becomes irregularly worn in consequence.

While, as already stated, the utmost care should always be taken to use only material of a uniform quality in the surface of the pavement, still under the closest inspection some inferior material may be used, which will only be shown when wear comes on the pavement, and unless then removed at once it will cause the evenness of the surface to be impaired about it. Irregular support from the foundation will be less likely to occur in good construction, but its effect will be similar to defective material, the sinking of individual bricks producing uneven wear. Weak spots in the foundation may sometimes be caused, where concrete foundation is not employed, by surface-water which is permitted to pass through the joints, saturating the sand or gravel beneath and causing it to move under concentrated loads. For this reason the joints should be observed during the early wear of the pave-

ment in order to remedy any case where they may not have been properly filled.

Where a brick pavement has been constructed of good material and kept in good surface during the early period of use, it may then reasonably be expected to wear out without any considerable expense for small repairs. The length of time the pavement may be expected to wear depends upon the quality of the materials and the method of construction. For the heavier traffic of many of the smaller cities, and streets of moderate traffic in the larger cities, brick has shown an endurance which indicates it to be a satisfactory and economical material.

In contracting for the construction of brick pavements, many cities require the contractor to guarantee the pavement for a term of years, making all necessary repairs during the period of guaranty. This is intended as an assurance of the quality of the work. A guaranty of the pavement for one year may often be of use in discovering any serious defects in construction, and will not add materially to the cost, but the engineer in charge of the work has means of accurately judging its quality and, where a long period of maintenance is required, it is doubtful whether the gain in quality is sufficient to warrant the increase in price necessitated by the guaranty.

CHAPTER IX.

ASPHALT PAVEMENTS.

ART. 66. ASPHALT

THE term *asphalt*, as commonly used, includes all of the solid bitumens which are used in the construction of street pavements. Some account of the classification and characters of these bitumens has been given in Chapter VI. The materials usually classed as asphalts include the true asphalts, gilsonite, and grahamite. Some residual pitches derived from the distillation of petroleums are also frequemtly called asphalts. In California, the residual pitches derived from asphaltic petroleums, as prepared for use in paving, are known as "*D*" *grade asphalts*, while in the East, residual pitches from some of the semi-asphaltic petroleums, used for road binders, are sometimes called *oil asphalts*.

The natural asphalts used in paving in the United States are obtained mainly from Trinidad and Venezuela, although they are found to some extent in the United States, Cuba, and Mexico. The most important supplies of native solid bitumen in the United States are the gilsonites, which are being used to considerable extent for street pavements. Grahamite has also been used in a small way.

TRINIDAD ASPHALT.

The most important source of supply of asphalt for street pavements in the United States is that of the

island of Trinidad, W. I. This asphalt is known as *lake asphalt* or *land asphalt*, according to the source from which it is obtained. Lake asphalt is found in a large deposit known as the pitch lake. This lake covers an area of over 100 acres, and lies in a deep crater with steeply sloping sides. The pitch seems to be, or to have been, forced up from below, and it is more or less in motion, excavations in the surface being gradually filled by flow of material from sides and bottom. Upon exposure to the air, the pitch slowly hardens, is somewhat softer near the center of the lake than at the sides, and it has been supposed that the supply from subterranean sources still continues to some extent. It has also been found that the surface of the lake is higher in the center than at the sides, and that the general elevation of the surface has been lowered somewhat by the large quantities of material which have been removed from it.*

In Trinidad lake asphalt, the bitumen occurs mixed with considerable quantities of finely divided mineral matter, as well as with water and small amounts of other impurities. In order to remove this water and any vegetable impurities which the crude material may contain, the asphalt is refined by heating sufficiently to vaporize the water and melt the bitumen. This is accomplished either by the use of a large kettle heated directly by fire, or by passing steam through pipes inside the tank containing the asphalt. During the heating the material is agitated by a current of air or steam. When the water has been driven off, and the material is thoroughly melted, the liquid asphalt is drawn off and is known as *refined*

* For a complete description of the Trinidad pitch deposits see the "Report of the Inspector of Asphalts and Cements of the District of Columbia," for 1891–92.

asphalt. In refining the asphalt no effort is made to remove the mineral matter, which is present in a finely divided state, and is utilized to replace sand or dust which must otherwise be added in forming the paving mixture.

Refined Trinidad Lake Asphalt consists ordinarily of about 54 per cent to 57 per cent bitumen, 5 per cent to 8 per cent of organic matter not soluble in carbon bisulphide, and 35 per cent to 38 per cent of mineral matter. The bitumens contain about 63 per cent to 66 per cent of malthenes (according to Richardson's classification), the remainder being asphaltenes, with sometimes about 1 per cent of carbenes. These asphaltenes contain considerable sulphur and are hard, brittle substances, which do not melt, but are readily soluble in the asphaltic oils. The non-bituminous organic matter is mainly material which seems to have been formed through oxidation of some of the harder bitumens of the asphalt. It contains a considerable amount of sulphur and may be considered, like the finely divided mineral matter, as of use as filler. The mineral matter in Trinidad asphalt is found in a finely pulverized condition and quite uniformly distributed through the mass.

Trinidad Land Asphalt is found in numerous deposits in vicinity of the pitch lake, most of them covered with soil. These deposits may have been formed either from the overflow of the lake or from independent sources, the action of which has long since ceased. The character of the land asphalt is more variable than that of the lake, and seems to depend upon the length of time it has been exposed to the weather. The bitumen of the asphalt undergoes a gradual hardening with time, the percentage of malthenes becoming less as compared with that of the asphaltenes. In some instances the amount

of mineral matter is greater, while the non-bituminous organic matter is increased by the changing of some of the bitumen to an insoluble condition.

Refined Trinidad Land Asphalt consists commonly of about 51 per cent to 55 per cent bitumen, 7 per cent to 10 per cent organic matter insoluble in carbon bisulphide, and 37 per cent to 40 per cent of mineral matter. The bitumen contains from 50 per cent to 63 per cent of malthenes, soluble in 88° naphtha solution. In the use of the land asphalts, larger quantities of fluxing materials must be employed to bring the material to proper consistency for use, and, on account of the variable character of the asphalt, much care must be taken in handling it to secure good results.

BERMUDEZ ASPHALT

Asphalt obtained from the Bermudez pitch lake in Venezuela is commonly known as *Bermudez asphalt.* This deposit is much greater in area than that at Trinidad, being some 900 acres in extent. It is, however, shallow in depth; not, as in Trinidad, in a deep crater, but spread out in a flat layer over the surface of the ground from a number of springs, some of which are still active. The depth of the deposit is from two to nine feet and covered with vegetation. The ground is flat and swampy, so that excavations fill with water, and in the rainy season the deposits are largely covered with water.

The asphalt has come from the spring in a soft condition, and afterward hardened upon exposure. Some of these springs are still active, and are surrounded by small areas of soft pitch raised above the general level of the deposit. The surface of the deposit in general is covered with a crust, probably due to coking produced by burning

vegetation, and this surface is cut through to obtain the asphalt from beneath. These deposits have been described* by Mr. Richardson, who has made a careful study of them.

The Bermudez asphalt is more variable in character than that from Trinidad. It contains very little mineral matter, and the bitumen is softer, carrying a higher percentage of malthenes. The crude asphalt contains considerable water and organic impurities, which are removed by refining as with the Trinidad asphalts.

Refined Bermudez Asphalt contains usually 93 per cent to 97 per cent bitumen, 2 per cent to 5 per cent of other organic matter, and 1 per cent to 3 per cent inorganic, or mineral matter. The bitumen contains 64 per cent to 72 per cent of malthenes soluble in 88° naphtha solution, and has 2 per cent to 5 per cent of petrolenes, volatile at 325° F. in 7 hours. It is therefore somewhat softer and more volatile than the Trinidad asphalt.

Another deposit of asphalt in Venezuela produces material known as "Maracaibo asphalt" somewhat similar to the Bermudez asphalt and used for paving.

UTAH ASPHALT

Considerable deposits of asphaltic materials are found in Utah and Colorado. Of these, the most important are large deposits of nearly pure bitumen known as *Gilsonite*. This material carries no mineral matter and is almost entirely soluble in carbon bisulphide. It does not therefore need refining or dehydrating before use. The proportion of malthenes is usually much less than

* On the Nature and Origin of Asphalt, Long Island City, 1898. The Modern Asphalt Pavement, New York, 1908.

that of the Trinidad asphalts, although there is considerable variation in the composition of the different veins. The character of the hydrocarbons is also quite different from those of the asphalts, the malthenes being mainly composed of unsaturated hydrocarbons. The Utah gilsonite is used to considerable extent for paving and also in the preparation of asphalt cement for filling the joints in brick and stone pavements, as well as asphalt paints and waterproofing mixtures.

CALIFORNIA ASPHALT

Several deposits of asphalt in Southern California have been developed and more or less used for paving purposes. The individual deposits in most cases are small in extent and somewhat expensive to work. The asphalt usually differs from those already described in being harder, the bitumen containing less malthenes. Some of them have a higher percentage of mineral matter and less bitumen than the Trinidad; others have only a small amount of mineral matter but are composed of a harder bitumen.

Bitumen similar to that in the natural asphalts is produced as a residual pitch in the distillation of the asphaltic petroleums of California. The character of this bitumen depends upon the extent to which the distillation is carried and the care used in the operation. These residues have been used to a considerable extent in paving under the name "*D*" *grade asphalt.* With proper manipulation of the process the product may be controlled and the proportions of malthenes and asphaltenes regulated. Where the material is overheated and burned, some of the asphaltenes are changed to carbenes, or to insoluble organic matter. Much care is therefore required for the preparation of good materials, and

failures have frequently resulted from the use of that which has been carelessly prepared and cracked. It is necessary that the residuum be prepared at a low temperature to prevent cracking. The following specification is given* by Richardson for "D" grade asphalt suitable for use in paving:

"'D' grade asphalt should be the residue from the careful distillation, with steam agitation, of some suitable California petroleum at as low temperature as possible and certainly not exceeding 700° F. It shall be free from carbon or suspended insoluble matter, which are evidence of excessive cracking.

"It shall be soluble to the extent of at least 98 per cent in carbon disulphide, 95 per cent in cold carbon tetrachloride and not less than 65 nor more than 80 per cent of it shall be soluble in 88° Pennsylvania naphtha, preferably nearer the former figure.

"It shall not flash below 450° F. and shall have a density between 1.04 and 1.06. It shall not volatilize more than 8.0 per cent at 400° F. in 4 hours, and shall have a penetration between 40° and 70°. It shall melt at not less than 140° nor over 180° F. on mercury, according to the method in use in the New York Testing Laboratory, and shall yield not more than 15 per cent of fixed carbon on ignition.

"It shall have a consistency of not less than four (4) mm. penetration at 78° F. when tested for five (5) seconds with a No. 2 needle weighted with 100 grams."

ASPHALTIC SAND.

Deposits of sand impregnated with asphalt occur at a number of points in California, Kentucky, Utah, and

* The Modern Asphalt Pavement, New York, 1908.

Indian Territory. These deposits consist of sand, or sandstone, saturated with bitumen. They differ from each other in the amount of bitumen found in them, and in the sand grains. They contain from about 5 per cent to 20 per cent of bitumen, which in most instances have a larger percentage of malthenes and are much softer than those of the Trinidad and Bermudez asphalts. They also frequently contain considerable petrolene, or matter volatile at 325° F. in 7 hours; in some instances as much as 10 per cent to 12 per cent. The bitumens of these materials may be classed as malthas rather than asphalts, and contain too much volatile matter for successful use as paving materials. They have been used to some extent in paving. In California the bitumen has been extracted from the sand by the use of naphtha and then refined and used in the same way as the Venezuela asphalts. The Kentucky asphaltic sandstones have been used by adding to them a harder bitumen, and finer mineral matter for filler. The Indian Territory material has been used for pavements by mixing it with an asphaltic limestone which also occurs in the same locality.

ROCK ASPHALT.

Limestone impregnated with bitumen occurs in many places in Europe and a few localities in the United States. The rock is mined at a number of places in Europe, notably at Seyssel, France; Travers, Switzerland; Ragusa, Italy; and Verwohle, Germany. It is usually composed of nearly pure carbonate of lime, impregnated with from 5 per cent to 20 per cent of bitumen. Natural rock asphalt suitable for paving purposes usually contains from 9 per cent to 20 per cent of bitumen. The rock should be of fine, even grain, and have the bitumen

uniformly distributed through it. In forming the surface material for pavements, the rock from different mines is commonly mixed in such proportions as to give about 10 per cent to 12 per cent of bitumen in the mixture.

Deposits of bituminous limestone exist in Texas, Indian Territory, and Utah in the United States. That of the Indian Territory has, as already stated, been used for paving in connection with asphaltic sand.

Art. 67. Asphaltic Cement.

Refined asphalt is brittle at ordinary temperatures and possesses little cementitious value. To bring it to a proper consistency it is heated to a temperature of about 300° F. and mixed with heavy bituminous oil, which serves as flux. The product is then known as *asphalt cement.*

Fluxes. The material commonly used to soften asphalt in preparing paving cement is the oil residuum resulting from the distillation of petroleum. These residuums are prepared as mentioned in Art. 45, and consist almost entirely of malthenes from which the petrolenes and lighter oils have been removed.

In the preparation of the residuums for this purpose, it is necessary that the distillation be carried far enough to remove all oils which may be volatilized at the temperature to which the material must be subjected in use, in order that the consistency of the cement remain constant. Beyond this point the extent to which the distillation should be carried depends upon the kind of asphalt and the service to which it is to be subjected. With dense and heavy oils a larger amount of oil must be used to reach the same consistency than with light oils, and the stability of the mixture is greater when

maintained in heated condition for a long time, on account of the less volatile nature of the oils. The character of the flux employed must be such as to give a proper relation between the percentages of malthenes and asphaltenes present in the resulting cement when brought to the required consistency. This is usually regulated in practice by specifying the penetration to be shown by the cement as well as the limits within which the percentage of malthenes to total bitumen may vary.

For Trinidad and Bermudez asphalts, fluxes made from either the paraffine, or the semi-asphaltic, petroleums have been found quite satisfactory, although the asphaltic oil when carefully prepared seems the more desirable. The dense residuums of the California asphaltic oils have not been found successful with these asphalts. The amount of residuum required for these asphalts varies from about 15 per cent to 25 per cent of the weight of the asphalt. If the residuum be so dense as to require larger quantities to flux the asphalt to the required consistency, the percentage of malthenes becomes too great and the cement is made more susceptible to temperature changes.

Asphaltic materials like gilsonite and grahamite containing less percentages of malthenes are fluxed by the use of heavy asphaltic residuums, which supply to the cement the lacking malthenes. Much larger proportions of flux must be used with these materials than are required for the Trinidad and Bermudez asphalts, the amount varying with the percentage of malthenes in the asphalt.

Natural malthas have sometimes been used as fluxes for asphaltic cement, but in most instances difficulty has been met in their use due to the fact that they contain considerable of the lighter oils, petrolenes, which are volatilized at the temperature required for mixing, thus

leaving the maltha too hard to act satisfactorily as a flux. The same difficulty is met in use of carelessly prepared petroluem residuum, which may lack uniformity of composition, and contain both volatile oils and hard asphaltenes.

Preparation of Cement. In preparing asphalt cement the asphalt is first melted and raised to a temperature. of about 300° F. The flux is then added at a temperature of 150° to 200° F. The mass is then agitated with jets of steam or air. The agitation is continued from 4 to 8 hours, or until the mass comes to a uniform and homogeneous condition. The refined asphalt cement is then drawn off. Careful and expert manipulation is necessary to secure a uniform product of proper consistency. Continued agitation with air causes hardening of some of the bitumens and volatilizes some of the lighter oils.

ART. 68. TESTS FOR ASPHALTIC CEMENT.

For the purpose of controlling the character of surface mixtures to be used upon asphalt pavements, tests are commonly made of the asphalt cement, as well as of the surface mixture itself. In testing asphalt cement the total amount of bitumen is usually determined; the hydrocarbons composing the bitumen are separated into their various classes, and the consistency of the mixture as well as the effect of temperature upon the consistency is examined. These tests are much the same as those given in Art. 48 for bitumen for road purposes, but vary in some particulars according to the use for which the material is intended. Tests for specific gravity, fixed carbon, and melting-point are there given and will not be repeated here.

Total Bitumen. The total bitumen in asphalt, or

asphalt cement, is determined by testing its solubility in carbon disulphide. The following method is recommended as standard by the "Committee on Standard Test for Road Materials," of the American Society for Testing Materials.*

"It was decided, owing to the great variety of conditions met in asphalt and like bitumen, that it was impossible to specify any one method of drying that could be at all satisfactorily applied in every case; it is therefore supposed that the material for analysis has been previously dried either in the laboratory or in the process of refining or manufacture, and that water, if present, exists only as moisture in the hydroscopic form.

"The material to be analyzed, if sufficiently hard and brittle, is ground and then spread in a thin layer in a suitable dish (iron or nickel will do), and kept at a temperature of 125° C. for one hour. In the case of paving mixture, where it is not desirable to crush the sand grains, a lump may be placed in the drying oven until it is thoroughly heated through, when it can be crushed down into a thin layer and dried as above. If the material under examination contains any hydrocarbons at all volatile at this temperature, it will of course be necessary to resort to other means of drying. Tar or oils may be dehydrated by distillation and the water-free distillate returned to the residue and thoroughly incorporated with it.

"*Analysis of Sample.* After drying, from 2 to 15 grams (as may be necessary to insure the presence of 1 to 2 grams of pure bitumen) is weighed into a 150-c.c. tared Erlenmeyer flask, and treated with 100 c.c. of carbon disulphide. The flask is then loosely corked and shaken from time to time until all large particles

* Proceedings, American Society for Testing Materials, Vol. VI, 1906.

of the material have been broken up. It is then set aside for 48 hours to settle. The solution is decanted into a similar flask that has been previously weighed. As much of the solvent is poured off as possible without disturbing the residue. The contents of the first flask are again treated with fresh carbon disulphide, shaken as before, and then put away with the second flask for 48 hours to settle.

"The liquid in the second flask is then carefully decanted upon a weighed Gooch crucible, 3.2 cm. in diameter at the bottom, fitted with an asbestos filter, and the contents of the first flask are similarly treated. The asbestos filter is made of ignited long-fiber amphibole, packed in the bottom of a Gooch crucible to the depth of not over $\frac{1}{8}$ inch. In filtering no vacuum is to be used and the temperature is to be kept between 20° C. and 25° C. After passing the liquid contents of both flasks through the filter, the residue on the filter is thoroughly washed, and the residues remaining in them are shaken with more fresh carbon disulphide and allowed to settle for 24 hours, or until it is seen that a good subsidation has taken place. The solvent in both flasks is then again decanted through the filter and the residues remaining in them are washed until the washings are practically colorless. All washings are to be passed through the Gooch crucible.

"The crucible and both flasks are then dried at 125° C. and weighed. The filtrate containing the bitumen is evaporated, the bituminous residue burned, and the weight of the ash thus obtained added to that of the residue in the two flasks and the crucible. The sum of these weights deducted from the weight of substance taken gives the weight of soluble bitumen."

Bitumen Soluble in Naphtha. This test is employed

for the purpose of determining the relative amounts of asphaltenes and malthenes present in the bitumen. When used in specifications it is designed to insure a proper relation between these classes of hydrocarbons, the object being to avoid materials containing too great percentage of asphaltenes, and the use of light oils as fluxes. The Committee of the American Society for Testing Materials recommend that the same method be employed as for obtaining the total bitumen. They also recommend that the naphtha used be described by giving the temperatures between which it distills and its specific gravity. Naphtha of a density of 88° Bé. at 60° F. is commonly employed for this purpose.

Bitumen Soluble in Carbon Tetrachloride. Tests of the solubility of solid bitumens in carbon tetrachloride are made for the purpose of determining the character of the bitumen through separating the carbenes from the asphaltenes. This test is commonly made in the same manner as is used in determining the solubility in carbon disulphide. The following method is given by the Association for Standardizing Paving Specifications, in 1911:

"Weigh off one gram of material, cover with 200 c.c. carbon tetrachloride, in Erlenmeyer flask, about 4:00 in the afternoon. Allow to stand over night in dark cupboard. Next morning, at 10 o'clock, Gooch crucible with felt is weighed and solution poured through. Wash with carbon tetrachloride, dry, at 100° C. and weigh."

Heat Test. This test is employed to determine the amount of the lighter and more volatile hydrocarbons in the bitumen. It separates the petrolenes from the heavier hydrocarbons (malthenes and asphaltenes). The test is made by determining the loss in weight suffered by the material upon being heated for a definite time at a constant temperature. It is designed to show whether

the asphalt cement will be materially changed by heat in forming the surface mixture.

Methods of making the test are given in Art. 48.

Penetration Test. The consistency of asphalt cement is determined by measuring the penetration of a No. 2 needle under a standard weight (usually 100 grams), in a given interval of time (commonly 5 seconds). The tests must be made at a standard temperature (usually 77° F.). Machines for making this test have been devised by Mr. A. W. Dow* and by Clifford Richardson.†

The Dow apparatus consists of a No. 2 needle inserted in a short brass rod which is held in an aluminum rod by a binding screw. The aluminum rod is secured in a framework so balanced that when it is supported on the point of the needle the framework and rod will stand in an upright position, allowing the needle to penetrate perpendicularly without the aid of support. The frame, aluminum rod, and needle weigh 50 grams; additional weight, when desired, is placed on the bottom of the frame. The motion of the sliding part is communicated by a thread to an index arm moving over a graduated disk.

"To make the penetration test, the samples of asphalt cement contained in circular tins, along with the glass dish, are placed in a receptacle containing at least 5 inches of water, which should have been previously brought to the temperature at which it is desired to make the test. While the samples are under the water it should be stirred every few minutes, best with a thermometer, and the temperature kept constant when necessary by the addition of hot or cold water as the case may require. The samples should

* Proceedings, American Society for Testing Materials, Vol. III.

† Proceedings, American Society for Testing Materials, Vol. VII.

remain under water at least 15 minutes, and in cases where their temperature is not near that at which the test is made they should be left in possibly half an hour. After the samples have remained in the water a sufficient time to have attained its temperature they are ready to be penetrated."

For the purpose of determining the effect upon consistency of changes of temperature, tests are made of the penetration at different temperatures. Mr. Dow recommends the following standards: "The needle which I have adopted as a standard for penetration is a No. 2, manufactured by R. J. Roberts, Redditch, England. All the needles, however, obtained in a package cannot be used for penetrating, as they vary somewhat in shape, and only those are selected which give a penetration corresponding to the standard needle. The standards that I have adopted for this machine are: At 32° F. or lower, the distance in one-hundredths of a centimeter that a No. 2 needle will penetrate into the sample in one minute of time when weighted with 200 grams. For tests made at a temperature of 77° F., the distance in one-hundredths of a centimeter that a No. 2 needle will penetrate into the sample in 5 seconds of time when weighted with 100 grams. For tests made at a temperature of 100° F., or above, the distance in one-hundredths of a centimeter that a No. 2 needle will penetrate in 5 seconds of time weighted with 50 grams.

"The following is a table giving the penetration and ductility of three classes of asphalt cement, which I have designated as A, B, and C:

	A	B	C
Penetration at —			
32° F.	10	13	25
77° F.	55	47	45
100° F.	150	110	75
115° F.	350	220	120
Ductility at 77° F.	300	75	20

"It has been found from practical experience that it is not safe to use an asphalt that is more susceptible to changes in temperature than sample *A*, given in the table, for if it were more susceptible than this, and made to a softness to give sufficient ductility at low temperatures, it would be too soft for use at high temperatures. The average paving cement gives penetrations such as represented by *B* in the table. Sample *C* in the table represents the least susceptible cement which I have found on the market. This non-susceptibility to change in temperature would be of great advantage if it were not for the fact that the cement is lacking in ductility. There is a law which I have found that invariably applies to the properties of asphalt cements, that is, that the less susceptible cement is to change in temperature, the less ductile it is at normal temperatures, and inversely, the more susceptible the more ductile is the cement."

Test for Ductility. Mr. A. W. Dow * has proposed a test of the ductility of asphalt cement by determining the distance in centimeters that a prism of cement can be drawn out before breaking. The prism he uses is 5 centimeters in length with a square cross-section of 1 centimeter. The test piece is molded with the ends in clips, which may be attached to apparatus for

* Proceedings, American Society for Testing Materials, Vol. III.

applying the pull. The clips are pulled apart at a speed of 1 centimeter per minute, while immersed in water at the required temperature. "Sufficient work has not been done on the ductility test at low temperatures to be able to state any standard at the present time, but it has been found that it is not safe for an asphalt having a consistency of 40 penetration at 77° F. to pull less than 20 centimeters at this temperature in the above ductility test."

Impact Test. An impact test for the purpose of determining the toughness of asphalt surface mixtures has been proposed by Messrs. Richardson and Forrest.* "The test pieces were made as follows: The surface mixture was brought to such a temperature as would be found necessary in handling it upon the street, a weighed amount, such as has been found by experience would yield a cylinder after compression of 1 inch in height, is placed in a cylindrical mold, closely resembling the ordinary diamond mortar of the laboratory, of a diameter of 1¼ inch. The mold is supported on the rigid block of timber 11¾ by 9½ inches square by 32½ inches high. The warm steel plunger is placed upon the top of the hot mixture, above which is a cylinder of steel weighing 10 pounds, running in grooved guides, which can be allowed to fall upon it from a height of 3 feet. After a few gentle taps to seat the plunger, the weight is raised and allowed to fall freely 10 times. The cylindrical mold is then inverted and the plunger introduced at the other end in a space left for this purpose by a boss on the base supporting the mold. Ten additional blows are then given on this end of the cylinder. In this way it has been found that satisfactory and uniform compression is obtained.

* Proceedings, American Society for Testing Materials, Vol. V.

The cylinders are then weighted to determine if the density is satisfactory, and measured to see that they are of uniform height, 1 inch or nearly so. On cooling they are ready to be tested, in the same manner employed by Mr. Page for rock cylinders, at whatever temperature may be selected" (see Art. 37).

Separation of Bitumen. For the purpose of testing the bitumen in surface mixtures, or in asphalt cement containing considerable mineral matter, it may be necessary to separate the bitumen from the mixture. The following method is given by Mr. Dow: * "The pure bitumen is obtained from an asphalt, or asphaltic cement, by extracting with carbon disulphide and evaporating off the solvent. The procedure that I have found to give the best results is as follows: Sufficient of the asphalt or asphaltic cement to give 30 grams of pure bitumen is placed in a large Erlenmeyer flask. Between 300 and 400 centimeters of carbon disulphide is added, the flask corked and then shaken from time to time until none of the asphalt is seen adhering to the sides or bottom, after which the flask is set aside and allowed to stand for 24 hours. The carbon disulphide is then decanted off carefully from the residue into a second flask. The residue is again treated with 200 or 300 cubic centimeters of the solvent and shaken as before. After the solutions in the two flasks have been allowed to subside for 24 hours, the contents are carefully decanted off on to an asbestos filter, passing the contents of the second flask through the filter first. The solvent containing the bitumen is then distilled in a flask until just sufficient remains to have the contents liquid. It is then poured into a flat evaporating dish and further heated

* Proceedings, American Society for Testing Materials, Vol. III.

on the steam-bath, stirring from time to time, until the greater part of the carbon disulphide is evaporated. About one-half cubic centimeter of water is next incorporated into the residue of bitumen and the heating continued over a burner until all foaming ceases, after which it is kept at 300° F. for 10 minutes. While heating over the burner the bitumen should be stirred constantly with a thermometer and care exercised that the temperature is kept constant at 300° F. It is doubtful whether in all cases the last traces of carbon disulphide are removed, even by this method, and it is also likely that the bitumen obtained in this way is often slightly harder than that contained in the original asphalt or cement; but its physical properties, as far as ductility and susceptibility to change in temperature go, will be relatively the same, and a sufficiently close approximation can be made of the consistency of the bitumen in the original sample to answer all practical purposes. As the removal of the last traces of carbon disulphide is very difficult, and a soft bitumen is liable to be hardened in so doing, I make it a practice, wherever it is possible, to extract the bitumen from an asphalt before it has been softened into the paving cement. In this way I find it easier to remove the last traces of solvent from this hard bitumen, and at the same time with relatively less hardening. This bitumen from the asphalt is then fluxed into a paving cement by adding to it an amount of flux equivalent to that used in making the paving cement from the asphalt. It is fortunate that nearly all the asphalts met with in commerce that are not pure bitumen are of a hard nature, so that the above method is applicable in practically all cases. This of course does not apply to bituminous rock, and

the only way possible to estimate their quality is by examining the extracted bitumen, which is done as just described. It is well to note here that in cases where the bitumen hardens materially in the removal of the solvent, such a bitumen will be rejected by hardening too much in the heat test."

Examination of Mineral Aggregates. For the purpose of determining the character of the mineral aggregate used in a surface mixture, or present in an asphaltic cement, the American Society for Testing Materials recommends* that it be passed through sieves of the following sizes in the order named.

Meshes per Linear Inch.	Diameter of Wire.	
	Inches.	Mm.
200	0.00235	0.05969
100	0.0045	0.1143
80	0.00575	0.1460
50	0.009	0.22865
40	0.01025	0.26035
30	0.01375	0.34925
20	0.0165	0.4191
10	0.027	0.6858

Tests Required by Specifications. Many tests have been proposed for the control of asphalt paving mixtures, or used in the study of asphalt materials, by various investigators. In general, however, specifications used by municipal engineers have depended upon a contractor's guaranty for the character of the work rather than upon inspection of the materials and workmanship. This has not proven altogether satisfactory and it is now common to have definite specifications for the materials employed and subject them to test in the city laboratories.

ART. 69. SURFACE MIXTURES.

The material commonly employed for the surfaces of asphalt pavements consists of a mixture of asphalt cement, powdered limestone, and sand. The mixtures used in different places have varied considerably in character, according to the nature of the materials available and the amount and consistency of the bitumen employed. Experience has gradually developed the practice in different places, the work at first being largely experimental, defects in the early work being corrected by modifications in later mixtures. Much of this work has been done by very haphazard methods and without any careful analysis of the causes of defects and failures, or of the differences in materials used in different places.

Sand. It is common to grade sand in size by sifting through sieves of 10, 20, 30, 40, 50, 80, 100 and 200 meshes to the linear inch, finding the percentage which passes each sieve and is caught by the next finer one. The portion which passes the 200-mesh sieve is too fine to be considered as sand, and is classed with the stone powder which is added as filler. The sands used for asphalt surface mixtures are much finer than those employed in cement mortars. In sand for this purpose most of the sand is usually fine enough to pass the 40-mesh sieve. In some instances, the bulk of the sand will pass through the 80 and 100-mesh sieves; in others, the larger portion will only pass the 40 and 50-mesh sieves. A grading of sizes in the sand is desirable on account of reducing the amount of voids to be filled by the asphalt, and frequently when a natural sand of correct sizes is not available, it is possible to secure a proper relation of sizes of

grain by mixing two or more sands of differing sizes. In general, sand so graduated as to leave a small percentage of voids is desirable in order that the interstices may be fully filled with bitumen, but the sand of greatest density is not necessarily the best for this purpose, as there may be instances where the percentage of voids would not admit of a sufficient amount of bitumen.

The voids in the sand are commonly tested by filling a measure with packed sand and then determining the quantity of water that can be added to it. A better method with fine material is to determine the specific gravity of the sand and also the weight of a given volume of it, the volume of voids being the difference between the measured volume and the volume of solid matter represented by its weight.

The sand used should be hard and tough in order to resist wear well, but its chemical character is not of special importance, although there seems to be a difference in the adherence of bitumen to the surfaces of different sands. The reason for this difference is not apparent and cannot be judged in advance of actual trial. The shape of grain does not usually appear important. Rounded grains often pack more easily and form a more dense mass, but it has been sometimes thought that they move more readily upon each other and form a less firm surface.

Filler. The filler used in asphalt paving mixtures consists of very finely ground mineral matter mixed with the bitumen for the purpose of rendering the surface more dense, and giving stiffness to it. The material commonly used for this purpose is ground limestone, although a number of other materials have been employed. Ground clay may make a good

filler; slaked lime, and Portland or natural cement are also used, especially good results being obtained with Portland cement.

The filler should be finely ground; nearly all of it is usually required to pass a 200-mesh sieve, but the finer portions are too fine to be graded by the use of sieves. For this purpose the method of elutriation may be employed. By this method the powders of different degrees of pulverization are separated by observing the times required to settle after being shaken in a vessel of distilled water, the portions which settle in 15 seconds, one minute, and 30 minutes being determined, and the relative fineness of different samples thus compared.

Composition of Mixture. The relative amounts of asphalt cement filler, and sand required for a surface mixture must of course depend upon the properties of these materials. The fineness of the sand and of the filler, and the amount of mineral matter in the cement, are all important in determining the proper proportions. The proportions of materials are determined by weight, the purpose being to secure a proper amount of bitumen and of dust, as compared with the sand in the resulting mixture. The amount of bitumen required varies from about 9 per cent to 13 per cent, most commonly between 10 per cent and 11 per cent. Mr. Richardson gives* the following mixture as a standard to be used for surfaces of Trinidad asphalt pavements:

* The Modern Asphale Pavement, N. Y., 1905.

	Surface Mixture.	Sand.
	Per cent.	Per cent.
Bitumen	10.5	....
Passing —		
200-mesh sieve	13.0	....
100-mesh sieve	13.0	17.0
80-mesh sieve	13.0	17.0
50-mesh sieve	23.5	30.0
40-mesh sieve	11.0	13.0
30-mesh sieve	8.0	10.0
20-mesh sieve	5.0	8.0
10-mesh sieve	3.0	5.0
	100.0	100.0

This he regards as an exceptionally good mixture. As the sands used in practice vary in the proportion of fine grain which they contain, the amount of bitumen must be correspondingly varied. When a larger portion of the sand passes the 80 and 100-mesh sieves, a larger amount of bitumen and of filler may be introduced. When the sand is coarser, a smaller amount of bitumen is necessary in order that the pavement may not be soft enough to mark under the horses' feet. In sand which lacks the finer grains the percentage of bitumen which can be used without marking is often so low as to leave the material too porous and liable to the action of water. It is desirable that the mixture contain all the bitumen that it will carry by the addition of filler without becoming too soft. A lack of bitumen may cause cracking of the surface. The quantity of bitumen required is also somewhat affected by the character of the sand grains and the extent to which the bitumen may adhere to and coat the grains. Some sands will "take" more bitumen than others of the same grading of sizes

without leaving a surplus of bitumen to render the material too soft.

The amount of bitumen to be used in a surface mixture is commonly tested by the pat test. This consists in pressing a pat of the surface material in a piece of brown manila paper and observing the stain left upon the paper; the depth of the stain indicates to the experienced eye whether the right amount of bitumen has been used and whether the mixture has been properly prepared. An impact test is also sometimes made to determine the resistance of the surface material to marking, and frequent analyses are made to test the correctness of the mixture.

The traffic to which a street is subjected has much to do with the consistency required in the surface mixture. For streets of light traffic a softer mixture should be employed than for one with heavy traffic. The rolling out and working of the surface by heavy traffic will admit of a hard surface material which might crack under light traffic. The surface mixtures must in every case be suited to the local conditions of traffic and weather, that it may neither mark under the impact of traffic nor crack from shrinkage in cold weather.

Method of Mixing. In the preparation of the surface mixture, the sand and asphalt cement are heated separately and then mixed while hot. When two or more sands are used to obtain the proper grading of sizes, this mixing must first be accomplished, and great care is necessary in handling the sand in mixer and heater to prevent the segregation of sizes and bring the sand in uniform mixture at proper temperature (about 330° to 350° F.) to the final mixture. The asphalt cement is also heated in a large heater where it is

agitated by steam jets to maintain the uniformity of mixture.

The surface mixture is prepared in a mixer of small size which mixes 10 to 15 cubic feet at one operation, and is so arranged as to load directly into the wagon which takes it to the street. The mixing is accomplished by blades revolving on shafts in the mixing tanks, requiring about one to two minutes to make a complete mixture. The proportioning of the ingredients is accomplished by weighing the proper quantity of each of the materials for a batch; the sand and filler are first introduced and mixed dry, and the asphalt cement then added and the whole mixed together. The mixture is then carried to the street at a temperature above 300° F.

Specification Requirements. The Association for Standardizing Paving Specifications has recommended the following specification for the composition of surface mixture for an asphalt pavement:

"The surface mixture shall consist of asphaltic cement, Portland cement (or stone dust), and sand proportioned by weight so that the resulting mixture will contain average proportions of the whole mixture as follows:

Mixture A.	Per Cent.
Bitumen soluble in cold carbon disulphide	11.0 to 13.5
Portland cement passing a No. 200 sieve	10.0 to 15.0
Sand passing a No. 80 sieve	18.0 to 36.0
Sand passing a No. 40 sieve	20.0 to 50.0
Sand passing a No. 10 sieve	8.0 to 25.0
Sand passing a No. 4 sieve	up to 10.0
Mixture B.	
Bitumen soluble in cold carbon disulphide	10.5 to 13.5
Stone dust passing a No. 200 sieve	10.0 to 15.0
Sand passing a No. 80 sieve	18.0 to 36.0
Sand passing a No. 40 sieve	20.0 to 50.0
Sand passing a No. 10 sieve	8.0 to 25.0
Sand passing a No. 4 sieve	up to 10.0

Sieves to be used in the order named.

"The item designated 'Portland cement (stone dust) passing a No. 200 sieve' within the limits named herein includes in addition to the Portland cement (stone dust) fine sand passing a No. 200 sieve not exceeding 4½ per cent of the total mixture, and such 200-mesh mineral dust naturally self-contained in the refined asphalt.

"Sand and asphaltic cement shall be heated separately to about 300° F. The maximum temperature of the sand at the mixers shall in no case be in excess of 375° F. at the discharge pipe. The Portland cement (or stone dust) shall be mixed with the hot sand in the required proportions, and then these shall be mixed for at least one minute with the asphaltic cement at the required temperature, and in the proper proportions in a suitable apparatus so as to effect a thoroughly homogeneous mixture.

"The proportions of asphaltic cement shall at all times be determined by actual wieghing with scales attached to the asphaltic cement bucket.

"The Portland cement (or stone dust) and sand must also be weighed unless a method of gauging approved by the (authorized city official) shall be used.

"The contractor shall furnish every facility for the verification of all scales or measures.

"The sand gradings and bitumen may be varied within the limits designated, in the discretion of (proper city official)."

Rock Asphalt. The preparation of surface material with rock asphalt consists only in crushing and grinding the rock to powder, and heating the powder to drive off the water and soften the bitumen, so that it may be compacted in the pavement. The powder is heated to a temperature of 200° to 300° F. and is applied hot in laying the surface.

Rock asphalt as it occurs in nature varies widely in character, and seldom has a proper composition for use in pavements without admixture of other materials. In determining the suitability of a material of this class for use, the character as well as the quantity of bitumen contained by it must be considered, and its deficiencies supplied in the materials added to it. This may sometimes be accomplished by mixing different grades of the asphaltic rock, or in other instances by adding other bitumens, or mineral matter.

In determing a mixture of asphalt rock, as in the case of other asphalts, the local conditions of climate and traffic must be considered and the quantity of bitumen be so proportioned as to remain solid in summer and not become brittle and lose cohesion in winter. The surface mixture for a rock asphalt pavement should ordinarily contain from 9 to 12 per cent bitumen The character of bitumen required is about the same as for a pavement made by mixing other asphalts with mineral matter.

ART. 70. CONSTRUCTION OF SHEET ASPHALT PAVEMENTS.

The work to be performed in laying a sheet asphalt pavement consists in grading and rolling the road-bed, placing the foundation, laying a binder course of bituminous concrete, and distributing and rolling the surface material so as to form a smooth surface. Sometimes the binder course is omitted, a thicker surface layer being employed to give sufficient stiffness and prevent the surface scaling from the foundation.

FOUNDATION.

Concrete base. As a sheet asphalt surface has no power to sustain loads, acting only as a wearing surface, which must be held in place from below, it is essential that it be placed upon a very firm, unyielding foundation. It is consequently nearly always placed upon a concrete base, which is commonly formed of hydraulic cement mortar and broken stone, prepared as described in Art. 57. In the use of this base, it is necessary that the mortar be fully set, and the concrete thoroughly dry before the asphalt is laid upon it, as the placing of the hot surface material upon a damp foundation will cause the blistering and possible disintegration of the surface by the steam generated from the base by the heat of the material.

For moderate or heavy traffic in cities, the concrete base is commonly made 6 inches thick. For lighter traffic a less depth, 4 inches or 5 inches, is sometimes employed. The depth necessary will depend upon the nature of the road-bed as well as the weight of the traffic. It should be greater as the subsoil is less firm and well drained.

Bituminous base. Sometimes a base has been used consisting of a layer of broken stone four or six inches thick rolled into place and coated with asphalt or coal tar paving cement. This is known as a *bituminous base.* The advantage which has been claimed for it is that the foundation and surface material become joined into a single mass, with the effect of anchoring the surface and preventing the formation of weathering cracks and wave surfaces, which are sometimes found when the hydraulic base and light surface layer are employed. The hydraulic base is commonly preferred

to the bituminous base, which is practically obsolete, because it forms an unyielding structure, not likely to be forced out of place by the weight of traffic at any point where the support of the road-bed may be weakened.

Macadam base. In surfacing streets with asphalt which have previously been macadamized, it is sometimes possible to use the old macadam as a base for the asphalt. This offers a good base in so far as it can be used without disturbance. It is difficult, however, to change the grade or reduce the crown without destroying the bond of the macadam. Old brick and stone pavements may also be used in the same way, where they can be used without disturbing them.

BINDER COURSE.

An intermediate layer known as the binder course is now commonly placed between the base and surface layer. This layer is ordinarily about 1½ inches thick and consists of broken stone, which passes through a 1 inch screen, mixed with sufficient bitumen to thoroughly coat the pieces of stone. The paving cement used in making the binder course should be of softer consistency than that used in the surface material, about 3 per cent of bitumen being usually required. The materials are mixed hot, laid and rolled in the same manner as the surface layer. This binder becomes consolidated with and gives added depth and strength to the surface, thus preventing the cracks and wave surfaces which may otherwise appear. The binder, as commonly formed of broken stone, is open and porous, but in some instances stone of graded sizes and sand are employed to make a dense bituminous concrete.

This is desirable practice, adding materially to the strength of the pavement under heavy traffic. It requires a larger amount of bitumen (about 5 per cent to 6 per cent) on account of the larger surface area of grains to be coated.

The binder course has, in some instances, been replaced by a coating of asphalt paint, consisting of asphalt cement dissolved in benzene. The surface of the hydraulic base is painted with this mixture, which serves to cement the base to the surface layer.

After the completion of the hydraulic base and when it has stood a sufficient length of time to harden and dry out, the binder course is placed and compacted. The binder is spread to uniform thickness over the base by use of shovels, all of the material being shoveled over in order to secure uniform compactness. It is then smoothed with rakes having long tines, and after partially cooling rolled with a 5 or 6 ton roller.

SURFACE COURSE.

Transportation. The materials for the binder and surface of asphalt pavements must be carried from the mixing plant to the street in some form of truck or wagon which will admit of the materials being delivered with small loss of temperature. Some form of dump wagon is commonly employed for this purpose, carrying from 2 to 4 tons of the materials at a load. The loss of heat is not rapid when the material is carefully handled and properly protected by tarpaulins, and the temperature of the mass should not be reduced more than about 10 degrees, where transportation to the street takes 2 or 3 hours.

Placing. As soon as the rolling of the binder course

has been completed, it is ready for the surface layer. This is usually 1¼ to 1½ inches thick where a binder course is used, or 2 to 2½ inches in single course work. The surface material is distributed by hot shovels from the piles into which it is dumped from the wagons, all the material being handled over as in the case of the binder. It is then spread into a smooth layer of proper thickness, with hot rakes, all lumps being broken and the material loosened up so that under the roller it may compact to a uniform density. After raking smooth, the surface is rolled with a steam roller. A light roller (2 to 4 tons) is commonly used for the first rolling until the material is sufficiently compact to bear the heavier one (usually weighing 6 to 8 tons), which completes the shaping of the pavement. A coating of dust, usually hydraulic cement, is given to the surface before the final rolling. This gives proper color to the surface.

The handling of the material necessarily varies somewhat with its character and requires, for good results, skill and experience on the part of the men in charge of the work. It is highly important that the material be so evenly distributed as to give a surface of uniform density; otherwise the surface may compress unequally under the traffic, becoming uneven and wavy. It is also necessary that the rolling be carefully done in order to properly compress the asphalt and bring the surface to the required form. When the surface is rolled out of shape through careless handling, it is difficult to bring it back again. The roller must be so balanced as to distribute the weight uniformly, a pressure of 200 to 300 pounds per linear inch of tire being required for the ultimate compression of the asphalt surface.

Rock asphalt. Pavements of rock asphalt are constructed in the same manner as those from free bitumen. The rock asphalt makes a harder surface and is more slippery than that made from free bitumen. It has never come so extensively into use in the United States. In Europe, where rock asphalt is very extensively used, pavements made from free bitumens mixed with sand are frequently denominated *artificial* asphalt as distinguished from *asphalt* or *natural asphalt,* by which is meant the rock found impregnated with bitumen.

In the European rock asphalt pavements the binder course is not so commonly employed as in the United States, and in many cases the finishing of pavement is by means of tampers and smoothing irons instead of rollers, the compression given to the surface not being so great, ultimate compacting being accomplished by the traffic. At the edges of the pavement and in places which cannot be reached by the roller, small hand tools such as hot smoothing irons and tampers are employed for finishing the surface. Sometimes also where the rolling has failed to compress the pavement into proper surface, it may be necessary to soften the surface with smoothing irons in order to reduce it to the required form.

ART. 71. ASPHALT BLOCKS.

Asphalt paving blocks are frequently formed of a mixture of asphalt cement and crushed stone. The stone used is mainly trap, or granite, broken so as to pass a $\frac{1}{2}$ inch screen. In early work, limestone was used; this was found to lack durability on account of the softness of the stone. The mixture is similar to

that used for the surface of a sheet pavement, containing about 8 per cent to 11 per cent of asphalt cement, 7 per cent to 10 per cent limestone dust, and crushed stone 80 per cent to 85 per cent.

The materials are heated to a temperature of about 300° F., and mixed while hot in an apparatus arranged to secure the even distribution of the ingredients through the mass. The thorough incorporation of the various materials in the mixture is of first importance in producing homogeneous and uniform blocks, while the quality of the materials used needs as careful inspection as in the case of the surface material for sheet pavements.

When the mixing is complete, the material is placed in moulds and subjected to heavy pressure, after which the blocks are cooled suddenly by plunging into cold water.

These blocks have usually been made larger than paving-bricks, the common size being 12 inches long, 3 or 4 inches wide, and 4 or 5 inches deep. They are laid in the same manner as brick, as closely in contact as possible, and driven together. Under the action of the sun and the traffic, the asphalt blocks soon become cemented together through the medium of the asphaltic cement, and form, like the sheet asphalt pavements, a practically impervious surface. They are often laid upon gravel base, although in the best work a light concrete foundation is employed.

In forming the asphalt block pavement the road-bed is brought to subgrade in the ordinary manner and rolled, leaving room for the pavement of uniform thickness to be placed upon it. A layer of gravel 4 or 5 inches deep is then placed and rolled, or a base of concrete is formed, with a cushion coat of sand 1 to 2

inches, and then the paving blocks. The blocks are pressed together in the courses by the use of a lever, and the courses driven against each other with a maul to reduce the joints as much as possible. A coating of sand is given to the surface of the pavement, and it is rammed to a firm and uniform surface, as in the case of brick.

These blocks have the advantage over sheet asphalt for the smaller cities, that the blocks may be formed at a central point and shipped ready for use to the site of the proposed pavement, and that no special plant need be erected in each town where they are to be constructed. They have given satisfaction in use, and have frequently shown good durability in wear under moderate traffic. It is claimed that they are less slippery and may be used upon steeper slopes than sheet asphalt. The cost of transportation of the blocks makes this pavement expensive in many localities not in close proximity to the place of manufacture, and prevents them from competing successfully with other pavements.

ART. 72. MAINTENANCE OF ASPHALT PAVEMENTS.

To give good service asphalt pavements must be kept clean. On account of the smooth surface and absence of joints, cleaning may be readily accomplished; and the presence of dirt, especially in wet weather when it is likely to cause the surface to remain damp, is liable to cause the asphalt to rot. More than any other pavement, therefore, the durability and wear of an asphalt surface depends upon its cleanliness. The presence of dirt upon asphalt in damp weather is also important in its effect upon the slipperiness of the pavement.

Small repairs of any breaks that may occur in an asphalt surface may be easily made, and such repairs should be constantly attended to in order to keep the surface in good condition. Small breaks will rapidly extend if they are not repaired at once. In making repairs to the surface of the pavement it is necessary to cut away the surface for a short distance about the imperfect spot, stripping the surface from the foundation and cutting the layer down square at the edges, after which a new piece of surface may be introduced to fill the hole in the same manner that the original surface was constructed. Such a patch may ordinarily be put on so as to make joints that will join perfectly with the old pavement and not show where it has been placed. When a surface has become so worn that patches would be numerous, the old surface may be stripped off and a new one placed upon the original foundation. When repairs are to be made upon a pavement having a bituminous base it is more difficult to cut out the holes in satisfactory shape, as there is no well-defined joint between the base and the surface layers.

The repairs that may be required upon an asphalt pavement depend, of course, upon the solidity of construction and the nature of the surface material. There is so great variation in the materials employed for the wearing surface that, as would naturally be expected, very considerable difference in wear is shown by different pavements.

It is common to require contractors for asphalt pavements to guarantee the pavement for a period of years, making all necessary repairs and leaving the work in good condition at the end of the period. This makes it an object for the contractor to do good work,

and may sometimes be the most effective way of securing it where so many elements of uncertainty enter. In general, it is not desirable to require contractors to guarantee paving for a long period on account of limiting competition and increasing unnecessarily the cost of the work. With asphalt paving, however, many engineers consider the difficulty of control during construction, under ordinary circumstances, such as to make a guaranty necessary, while the fact that the material is for the most part controlled by a few large companies renders the guaranty less undesirable as restricting competition. This method has, however, been found unsatisfactory in many instances, on account of the difficulty of enforcing the guaranty.

The cost of maintenance of asphalt pavements varies widely in different places, depending upon the character of the construction used and the local conditions surrounding the pavement. In Washington, D. C., the average life of the surface before renewal is about 20 years, while the annual cost of maintenance is about 2.5 to 2.8 cents per square yard per annum. In locations where the surface is kept continuously damp, particularly if it is not kept clean, the asphalt is apt to deteriorate rapidly and, in some instances, scales off and gradually disintegrates. The resistance of asphalt to water action depends very much upon the density of the surface mixture and the ease with which water may penetrate it. Great care should be used in laying pavements where moisture conditions are not good to secure a dense surface mixture in which the voids are well filled. Where water may continuously run in the gutters, it is usually better to construct the gutters of other material less affected by the action of water.

Injury to asphalt surfaces from illuminating gas

escaping from leaking mains has been observed by Mr. A. W. Dow at Washington, D. C. The heavy hydrocarbons of the gas are absorbed by the bitumen of asphalt, which is thereby softened and caused to cut and flow under the traffic.

The cost of maintenance depends largely upon the system employed in the maintenance work. In some cities repairs are made only at considerable intervals when the surface is in bad condition, and in such instances the ultimate cost is usually much larger than where small repairs are made as they are needed to keep the surface always in good condition.

ART. 73. BITULITHIC PAVEMENT.

The name "bitulithic" is commonly applied to a pavement, the surface of which is composed of a bituminous concrete, the aggregate being a mixture of several sizes of broken stone, so proportioned as to give a dense material with a small percentage of voids. Pavements of bituminous concrete have been occasionally constructed for a number of years, but the introduction of this type of pavement upon a considerable scale began about 1901, when exploited under a patent of the Warren Brothers, and most of those since constructed have been under this patent.

In the construction of pavements of this class the crushed rock is screened into several sizes, which are then mixed together in such proportions as to produce an aggregate with very small percentage of voids. Four to six screens are used, varying from about 1½ inches to $\frac{1}{10}$ inch openings. Sufficient quantities of the smaller sizes are employed to fill the interstices in the larger sizes; the relative proportions being determined

in each instance by experiment upon the particular material in use. "After the proportions have been determined, the mineral material is passed through a rotary screen which separates it into several different groups of sizes. The proper proportion by weight of each of these sizes is secured by the use of a scale having seven beams, the exact required amount being weighed out and run into a double shaft rotary mixer. There it is combined with a bituminous cement which is also accurately weighed in the proper proportion. The whole is then thoroughly mixed together and dumped, while still hot, into carts, hauled to the street, spread, and thoroughly rolled with heavy steam road rollers.

"After the surface is thoroughly rolled, a flush coat of quick drying bituminous cement is applied to the surface. There is then applied a thin layer of hot finely crushed stone, varying from $\frac{1}{4}$ to $\frac{3}{4}$ inches in size, according to the roughness of the surface desired. The pavement is again heavily rolled, leaving the street in a finished condition."

These pavements are commonly constructed upon bituminous foundations (see Art. 58). When the sub-foundation is not firm, and concrete foundations are required, the surface of the concrete is roughened by scattering stone of about $1\frac{1}{2}$ inch diameter lightly over it, and ramming the stones into the concrete to about half their depths. This forms a bond between the base and surface of the pavement, and prevents the creeping of the surface.

These pavements have been used with good success in many places throughout the United States. They require care and skill in construction, both in securing proper grading of the mineral aggregate and in the character and proportions of the bituminous cement.

It is claimed by the advocates of this kind of construction that, on account of the density and firmness of the mass of stone of which they are composed, a softer bitumen may be employed, thus eliminating the danger of cracking in cold weather. In some instances, where hard stone has been used in forming the surfaces, there are indications that this construction will give better resistance to wear than the ordinary asphalt surface, but longer experience is necessary to fully test its durability. It has been successfully used upon much steeper grades than sheet asphalt, being reported as affording a good foothold to horses, and satisfactory in one instance upon a 12 per cent grade.

In constructing these pavements, as with sheet asphalt, it has been customary to rely upon the contractor's guaranty for securing good work and no attempt is usually made to determine the character of the bituminous cement by direct tests. This is an undesirable feature of most work with these materials, and it is to be hoped that, as better information concerning the bitumens becomes available, more satisfactory specifications may become feasible. The following is an extract from the specifications used in St. Louis in 1908:

"Upon the foundation shall be laid the wearing surface, which shall be composed of carefully selected sound, hard crushed stone, mixed with bituminous cement and laid, as hereinafter specified.

"The stone last referred to shall have a percentage of wear not to exceed 5 per cent when tested in the following manner:

"The sample to be tested shall be broken into pieces that will pass, in all positions, through a 6 centimeter ring, but not through a 3 centimeter ring. The

fragments of stone shall then be cleaned, dried in a hot air bath at 100° C. and cooled in a dessicator, after which five kilograms shall be weighed out and placed in a cylinder of an abrasive machine and the cover bolted on. This machine (see Art. 37) shall consist of a cast iron cylinder, or cylinders, fastened to a shaft so that the axis of each cylinder makes an angle of 30 degrees with the axis of rotation. Each cylinder shall be 20 centimeters in diameter and 34 centimeters in depth; shall be closed at one end and shall have a tightly fitting cover at the other end. After this, the machine shall be rotated at the rate of 2000 revolutions per hour for five hours. When the 10,000 revolutions of the machine are completed, the contents of the cylinder shall be placed on a sieve of 0.16 centimeter mesh, and the material which passes through carefully collected and weighed. The ratio between the weight of the fine material and the original five kilograms placed in the cylinder is the percentage of wear.

"After immersion in water for a period of ninety-six hours, a smoothly worn fragment of stone weighing between 20 and 60 pounds shall not absorb more than 3 pounds of water per cubic foot of stone.

"After heating the stone in a rotary mechanical dryer to a temperature of about 250° F. it shall be passed through a rotary screen having six or more sections, with varying sized openings, the maximum of which shall not be larger than one and one-half inch, and the minimum one-tenth of an inch in diameter. The several sizes of stone thus separated by the screen sections shall pass into a bin containing six sections or compartments. From this bin the stone shall be drawn into a weight box, resting on a

scale having seven beams. The stone from each bin shall be accurately weighed in the proportions determined by laboratory tests that will give the greatest density of mineral aggregate and the greatest inherent stability of the mineral aggregate. From the weigh-box each batch of mineral aggregate composed of different sizes, accurately weighed, as above described, shall pass into a "twin pug" or other appropriate form of mixer. If the proportions of crushed stone in the mixer do not provide enough fine particles to bring the aggregate to the density desired, there may be added not to exceed 15 per cent of fine sand, gravel, hydraulic cement, and pulverized limestone. To the stone in the mixer shall then be added a sufficient quantity of Warren's Puritan Brand No. 21 Bituminous Water-proof Cement, to thoroughly coat all the particles of stone and fill all the voids in the mixture. The bituminous cement shall, before mixing with the stone, be heated to between 200 and 250° F. and the amount used in each batch shall be accurately weighed and used in such proportion as have been previously determined by laboratory tests to give the best results and fill the voids in the mineral aggregate. The mixing shall be continued until the result is a uniform bituminous concrete. In this condition it shall be hauled to the street and there spread on the prepared foundation to such depth that after thorough compression with a steam roller it shall have a thickness of two inches. The proportion of the various sizes of stone and of bituminous cement shall be such that the compressed mixture shall have as nearly as possible the density of solid stone.

"After rolling the wearing surface, there shall be spread over it a thin coating of Warren's Quick

Drying Bituminous Flush Coat Composition in a plastic condition, for the purpose of closing any pores or cellular openings, and to thoroughly fill any unevenness or honeycomb which may appear in the surface. There shall then be applied thereto and combined therewith while plastic, stone chips, with the same qualities required of the stone in the pavement proper, by rolling the same into the surface with a heavy steam roller for the purpose of presenting a gritty surface.

"In order to get the greatest possible density, the pavement shall be rolled continuously from the time the bituminous concrete is brought upon the street until the stone chips have been rolled into the surface and the roller no longer makes a perceptible impression upon the pavement.

"Each layer of the work shall be kept as clean as possible so as to readily unite with the succeeding layer. The bituminous compositions shall in each case be free from water, petroleum oil, water gas, or process tars and shall be especially refined with a view of removing the light oil, naphthaline and other crystalline matter susceptible to atmospheric influences."

CHAPTER X.

WOOD-BLOCK PAVEMENTS.

Art. 74. Types of Wood-Block Pavement.

The use of wood blocks for the surfaces of pavements began a little before 1840, and since that time many types of construction have been tried with varying degrees of success. The first pavements in London, in 1839, consisted of hexagonal blocks of fir, six to eight inches in diameter and about six inches deep, placed on a base of gravel. In 1841 a pavement of round beech blocks was laid upon a foundation of planks and sand. The wood soon decayed and the pavement was removed.

In Philadelphia, square hemlock blocks were laid in 1839 and hexagonal hemlock blocks probably a little earlier. Both were quickly destroyed by the decay of the blocks. In New York and Boston similar pavements were constructed at about the same time and with much the same result.

In 1855 a pavement of tamarac blocks was laid in Quebec. This pavement was placed upon a base formed of a flooring of one and one-half inch boards laid longitudinally and crossed at right angles by a second flooring of inch boards. A layer of sand one-half inch thick was placed over the boards. The tamarac blocks were ten to fifteen inches in diameter and twelve inches long, small pieces of wood being forced into the spaces between the blocks. The

joints were filled with a mixture of sand, cement, and tar. This heavy construction is reported as having given very good wear, with no decay.

Cedar Block Pavements. In the earlier wood pavements of the United States, cedar blocks were commonly employed. These blocks were used in the form of whole sections of the tree on account of the liability of the wood to split off between the layers when cut to a rectangular shape, as well as to reduce waste to a minimum. They usually varied from 4 to 9 inches in diameter and 4 to 8 inches in depth. In some cases the blocks were cut to a true cylindrical form, the sapwood as well as the bark being cut away by passing the block through sets of knives, gauged to turn out true cylinders of given size. The use of sapless blocks increases the life of the pavement by augmenting the resistance of the material both to the wear of traffic and to the disintegrating influences of the atmosphere.

These pavements were usually placed upon a foundation of boards laid upon sand. The planks were commonly tarred and laid lengthwise of the street, being nailed to scantling or other boards placed across the street and bedded in the sand. This construction has the disadvantage of lacking firmness as well as of being perishable, although in some instances good results have been obtained by its use.

The construction of a pavement of this type is shown in Fig. 25. Blocks of varying sizes are employed, being set in contact with each other in such a way as to leave the spaces between the blocks as small as possible. Usually the joints are filled with sand and gravel, sometimes with a coating of tar; or in some cases the joint is partially filled with tar and then completely filled with sand or small gravel. When the

ordinary coal-tar paving cement filling is used, the joints are first filled nearly full of sand or gravel, which is pounded down with a bar, after which the hot cement is poured in until the joint is well filled.

These pavements, on account of the plentiful supply of timber were constructed for very low first cost and undoubtedly served a very useful purpose in many instances, permitting the improvement of many streets to an extent which at that time would have otherwise been impossible. They lifted the streets out of the mud, although the pavements did not usually last long

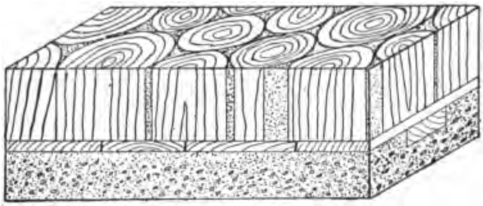

FIG. 25.

and were afterward replaced by more durable materials. Pavements of this type wear rapidly under traffic, soon becoming uneven, and their use has, for the most part, been discontinued on account of their lack of economy.

Nicholson Pavement. Rectangular wooden blocks set like the cedar blocks, upon a plank foundation were at one time quite extensively used and known as Nicholson pavements. In these pavements the blocks are set with their longest dimension transverse to the length of the street. They are usually arranged in courses across the street, being placed close together in the courses, and arranged to break joints in adjoining courses. Between courses a joint is usually made ½ to

½ inch in width for the purpose of affording a foothold to horses. In the older pavements of this character a much wider joint was employed, some as much as an inch in width, with the idea that they were necessary to secure proper foothold. The joints were filled in the same manner as in the round block pavement. These pavements like the cedar blocks have given place for the most part to more economical kinds of construction.

Rectangular Blocks on Concrete. The use of a concrete base under a surface of the Nicholson type effected a marked improvement in the wear of the pavement.

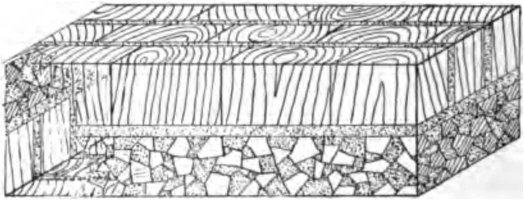

FIG. 26.

Round block pavements were also sometimes placed upon a concrete foundation.

In using a concrete foundation a cushion coat of sand is commonly employed on top of the concrete in which to bed the blocks in order that they may be brought to an even surface. Sometimes a thin layer of cement mortar is used in place of the sand upon the concrete; and in London some pavements have been constructed with a thin layer, about ½ inch, of asphalt mastic over the concrete, the blocks resting upon the mastic.

A pavement of this type is shown in Fig. 26.

In laying a pavement of this kind a course of blocks

is first set across the street, and then a strip of wood of the thickness of the joint is set against the row of blocks and left until the next course is placed, or sometimes spuds with heads of the thickness of the joints are driven to the head in the side of each block, and the next row of blocks are set against the spuds.

In some pavements of this kind hydraulic cement is employed in filling the joints, and in some instances the lower half of the joint is filled with coal tar paving cement and the upper half with hydraulic cement mortar. The cement mortar gives a harder wearing surface, and protects the pitch from the softening action of the sun in warm weather. In later practice the width of joint has been gradually reduced until the blocks are set in contact with each other, occasional expansion joints being provided.

These pavements have been extensively used in England, and to a smaller extent in the United States. They have been fairly satisfactory in use but have been, for the most part, superseded by treated blocks.

Treated Block Pavement. Wood blocks treated by some preservative process for the purpose of preventing decay and of hardening the block so as to give better resistance to wear have come into use somewhat extensively since about 1900. These pavements have given good service in use, under heavy traffic in the business sections of the large cities, and on important residence streets, where the somewhat high cost is not prohibitive. The use of untreated blocks has been practically abandoned as uneconomical.

ART. 75. WOOD BLOCKS.

Wood-block pavements are constructed of blocks set with the fibers vertical, so that wear comes upon the

ends of the fibers and has no tendency to split pieces off from the blocks. These blocks are usually from 6 to 12 inches in length, 3 to 4 inches in width, and 3 to 4 inches in depth. Some engineers require the blocks to be of uniform length but a variation of from about 6 to 10 inches is more common and seems desirable because of the greater freedom in obtaining timber for the purpose. A depth of 3½ inches, or at most 4 inches, is sufficient and there seems to be no advantage in greater depth, as the block would become unserviceable and need to be renewed before this depth would be worn away. The blocks are cut from planks of uniform thickness, and are set in courses across the street, the blocks in adjoining courses breaking joints with each other.

Kinds of Wood. Wood for pavements should be close-grained and not too hard. It should be as homogeneous as possible in order that the wear may be uniform, and soft enough that it may not wear smooth and slippery. The blocks should always be subjected to careful inspection, and only sound and well-seasoned timber should be employed. Blocks containing shakes and knots should be rejected, and when untreated blocks are to be used, all sapwood needs to be removed in order to lessen the liability to early decay.

In Australia hard-wood blocks have been quite extensively used and are reported as giving good service, although they are admitted to be somewhat slippery in wet weather. Australian *Karri* and *Jarrah* woods are employed, and it is claimed for them that they show unusually great resistance to wear and are not soon affected by decay. These woods are too dense for preservative treatment and are used in the form of untreated blocks.

In London, where wood pavements have been very extensively employed, Swedish yellow deal is commonly placed at the head of the list of woods in value, yellow pine and Baltic fir being also largely used and considered good in use. The Australian woods above mentioned have also been used to some extent in London, and are said to have given very satisfactory service, showing greater resistance to wear than deal or pine, although somewhat expensive. Deal treated with creosote is extensively used and seems to give the best satisfaction. In Paris, teak, karri, and pitch pines are frequently employed, although treated native pines are more commonly used and have been found to give good service.

In the United States, Southern yellow pine has been most extensively employed, and seems to have given the best satisfaction in use, but is so much in demand for other purposes that properly selected timber is rather expensive. Norway pine, tamarack and Southern black gum are also used to some extent and have given good service. White birch and hemlock have also been successfully tried for this purpose, although they have only been used in experimental pavements. All of these woods are used as treated blocks, and are readily susceptible to impregnation with the creosote oils used in treatment.

The specifications used in New York City in 1911 require the blocks to be of Southern long-leaf yellow pine or of Southern black gum, while the St. Louis specifications permit the use only of the Southern long-leaf yellow pine blocks, which must meet the following requirements:

"Each block shall consist of at least seventy-five (75) per cent heart, and shall be free from bark, large, loose or rotten knots, and shakes or other defects. No

dead or second-growth timber will be accepted, and all timber shall be cut in a locality recognized as producing the timber described.

"The number of annual rings shall average not less than six (6) per inch, measured radially. All timber for the blocks shall be thoroughly air-seasoned."

It is customary to require that the timber shall be subject to inspection at the works, before being cut into blocks, or treated with oil.

The specifications adopted by the Association for Standardizing Paving Specifications in 1911, contain the following requirements:

"The wood to be treated shall consist of Southern yellow pine, Norway pine, black gum and tamarack, only one kind of wood, however, to be used on any one contract.

"Yellow pine blocks shall be made from what is known as Southern yellow pine, well manufactured, full size, saw-butted, all square edged, and shall be free from the following defects: unsound, loose and hollow knots, worm holes and knot holes, through shakes and round shakes that show on the surface. In yellow pine timber the annual rings shall average not less than eight to the inch, and shall in no case be less than four to the inch measured radially.

"Norway pine block, gum and tamarack block shall be cut from timber that is first class in every respect, and shall be of the same grade as that defined for the Southern yellow pine.

"The blocks shall be from 5 to 10 inches long, but shall average 8 inches; they shall be three and one-half ($3\frac{1}{2}$) and four (4) inches in depth, according to traffic; they shall be from three (3) to four (4) inches in width; but all blocks in one street or improvement shall be of

uniform width, provided that blocks 3 inches in depth can be used on residential streets and in alleys; provided, further, that in no case shall the width and depth of blocks be equal.

"A variation of one sixteenth ($\frac{1}{16}$) of an inch shall be allowed in the depth and one eighth ($\frac{1}{8}$) of an inch in the width of the blocks."

ART. 76. TREATMENT OF WOOD BLOCKS.

The most serious objection commonly raised to the older type of wood pavement is that wood, being porous, absorbs moisture readily, and is thus liable both to destruction through decay and to become injurious to health. Various methods were therefore proposed for rendering the blocks less pervious and more durable by impregnating them with various substances which fill the pores and act as preservatives. The earlier attempts in this direction were not in the main successful and little seemed to be gained in durability by the treatment. Solutions of mineral salts were tried but were found unsuitable for the purpose. Creosoting the blocks, which consists in impregnating the wood with the oil of tar, or creosote, was more successful, but with the type of construction in use seemed of doubtful economic value.

In the process of creosoting, the wood is first thoroughly dried, usually by heating it in a kiln, and the hot creosote is then forced in under pressure. The method of accomplishing this varies in different places. In order to be effective the process must be thoroughly carried out and the pores well filled. It has been commonly recommended that from 8 to 12 pounds of creosote

per cubic foot of timber should be forced in, as a minimum requirement for the softer woods, such as are commonly used in pavements. Creosote has the property of destroying the lower forms of animal life, and is therefore an effective preservative against destruction through these agencies where they exist. It is therefore often employed for the preservation of timber for subaqueous construction in sea-water. This process, when properly applied, is effective in preventing decay, and therefore in lengthening the natural life of the wood. It also renders the wood less permeable and thus removes the objection to the old form of pavement based upon its absobent nature.

The earlier efforts to increase the life of wood pavements by the use of creosoted blocks were rather unsuccessful. The resistance of the wood to the wear of the traffic did not seem to be materially affected by the treatment given, and the failure of the pavement being ordinarily from wear rather than from decay, the life of the pavement was not materially prolonged. More recently, however, careful methods of treatment have produced blocks which show high resistance to wear, and give good results under the heavy traffic of the large cities. The present treatment is more thorough, a larger quantity of oil being injected, and in most instances, heavier oils being employed. The object is to waterproof the blocks by completely filling the pores of the wood. It is also claimed that heavy oils harden in the pores and add to the resistance to wear by preventing displacement of the wood fiber, when subjected to loads or blows.

The heavy oil of tar, known as creosote oil in the preservation of timber for other purposes, is commonly used, but is frequently combined with other materials intended to give greater stability and more thorough

waterproofing. There is much difference of opinion concerning the efficiency of the various oils employed.

Creo-resinate Process. Many of the pavements now in use have been constructed by the creo-resinate process. In the creo-resinate treatment, the wood is impregnated with a substance consisting essentially of a mixture of the oil of tar with resin, the resin acting as the waterproofing and hardening material. The amount of resin required varies from about 25 per cent to 50 per cent of the mixture, and depends upon the character of the oil used, a heavy dense oil requiring less resin than a lighter and more volatile oil. The method of treatment is thus described by Mr. F. A. Kummer: *

" Blocks, after being cut to size, are placed in circular cages made of band steel of approximately the diameter of the cylinders in which the treatment takes place, and are then, while in these cages, run into the cylinders on cars. The cylinders themselves are usually about 6 feet in diameter and somewhat over 100 feet long, and are provided with steam coils along the bottom and sides to provide heat for drying and preparing the lumber for treatment. The blocks are heated in this way, some works employing live steam instead of steam coils, and others a combination of the two. After several hours both by the use of heat and by the use of a vacuum pump, a large portion of the moisture and light volatile oils in the wood, if the latter contain any such, are driven off. The preservative material is run into the cylinder under a vacuum and hydraulic pressure of 200 pounds per square inch, applied from two to three hours, or for such longer period of time as may be necessary to thoroughly treat the charge, the result being

* Engineering Record, August 25, 1906.

accomplished when the gauges show that no more material is entering the wood."

This method was specified for a number of years in the City of New York, but is no longer required on account of the high cost.

Creosote Oil. Sometimes so-called creosote oil is used without the admixture of heavier materials. The advocates of this method claim that a more thorough impregnation of the wood is possible than with the heavier materials, that the results are equally good in durability, and that the material is more easily obtainable. The character of the oil used is shown by the following extract from specifications recommended by the Wyckoff Pipe and Creosoting Company. These specifications require the injection of at least 18 pounds of the oil into yellow pine blocks:

"The creosote oil shall be a dead oil of coal tar or coal-tar product. It shall not contain more than 3 per cent of water and if it does contain this amount of water a corresponding correction must be made so that an equivalent additional amount of creosote is forced into the blocks. It shall contain only traces of acetic acid and acetates. Its specific gravity at 100° F. (38° C.) shall be at least 1.03 and not more than 1.07 so as to assure its thoroughly penetrating the wood blocks. The residue insoluble by filtration with benzol and chloroform must not exceed 3 per cent of the weight of the creosote oil. Fractional distillation of 100 grams of the creosote oil shall produce percentages of dry oil by weight within the following limits:

Up to 150° C. (302° F.)	not to exceed	2%
Between 150° C. (302° F.) and 170° C. (338° F.)	not to exceed	1.5%
Between 170° C. (338° F.) and 235° C. (455° F.)	not to exceed	35%
Between 235° C. (455° F.) and 300° C. (572° F.)	not to exceed	35%

The residue remaining shall be soft and adhesive. The creosote oil shall contain about 25 per cent of crystallizable naphthalene and at least 15 per cent anthracene oils. At least 95 per cent of the creosote oil shall be soluble in carbon bisulphide and equally in absolute alcohol."

Heavy Tar Oils. The use of tar oils of greater specific gravity than the ordinary creosote oils, has been rapidly developing in the past few years. These c ls are produced by adding coal-tar pitch to creosote oil so as to obtain an oil of proper consistency. It is claimed by advocates of these oils that they more completely waterproof the block, and make it more resistant to wear. The Association for Standardizing Paving Specifications has recommended this method of treatment. These specifications have been criticised on the ground that the oil is difficult to obtain and is a monopoly. This, however, the association does not think to be the case. The objection is also made that these heavy tar oils make a pavement which becomes sticky and disagreeable in hot weather. The association, however, are of opinion hat this is the most desirable method of treatment, and in 1911 adopted the following specifications:

Preservative. The preservative to be used shall be a coal-tar product, free from adulteration of any kind whatever, and shall comply with the following requirements:

1. The specific gravity shall not be less than 1.10 or more than 1.14 at a temperature of thirty-eight (38) degrees Centigrade.

2. Not more than three and one-half ($3\frac{1}{2}$) per cent of the oil shall be insoluble by hot continuous extractions with benzol and chloroform.

3. On distillation, which shall be made exactly as

described in Bulletin No. 65 of the American Railway Engineering and Maintenance of Way Association, as shown in the appendix to these specifications, the distillate shall not exceed two (2) per cent up to 150 degrees Centigrade, and shall not be less than thirty (30) or more than forty (40) per cent up to 315 degrees Centigrade.

4. The manufacturer of the oil shall permit full and complete inspection and sampling at the factory at which the oil is produced, of all materials either crude or refined, entering into the manufacture of the finished product, as well as the finished product itself, in order that the materials used can be determined to be in accordance with the foregoing requirements. He shall also submit satisfactory proof of the origin of all materials entering into the composition of the finished product.

Samples of the preservative taken by the inspector from the treating tank during the progress of the work shall at no time be allowed to show an accumulation of more than two (2) per cent of foreign matter, such as sawdust and dirt.

Due allowance shall be made for such accumulation of foreign matter by injecting an additional quantity of oil into the blocks.

Treatment. The blocks shall be treated with the preservative elsewhere described, so that the pine and tamarack blocks shall contain not less than twenty (20) pounds, and the gum blocks not less than twenty-two (22) pounds per cubic foot.

This amount may be reduced to sixteen (16) pounds, under conditions of heavy traffic in the discretion of the engineer.

Inspection. The party manufacturing the blocks shall equip his plant with all necessary gauges, appliances and facilities to enable the inspector to satisfy himself

that the requirements of the specifications are fulfilled.

Art. 77. Tests for Wood Blocks.

Specification requirements for wood blocks vary widely in different places throughout the country and no systematic method has been adopted for the inspection and testing of the blocks. A number of tests have been proposed for use both at the plant where the blocks are treated and after the blocks have been delivered at the site of the pavement. Inspection of the blocks is frequently made before treatment, as well as tests of the oil to be used in the treatment, an inspector being kept at the plant for the purpose while the blocks are being prepared. The thoroughness of the treatment is determined by the difference in weight of treated and untreated blocks.

For the examination of wood blocks after their delivery at the point of use, several tests are in use or have been proposed:

a. The blocks are inspected as to their size, shape, and freedom from defects.

b. Blocks may be split and examined as to the thoroughness of the treatment, and a weight test applied to determine whether a sufficient quantity of oil has been absorbed by the block.

c. Tests of absorption are made by first drying the blocks and then soaking them in water, thus determining the amount of water that may be absorbed.

The 1911 specifications of the City of New York contain the following requirement:

"After treatment the blocks are to show such waterproof qualities that after being dried in an oven at a temperature of 100° F. for a period of 24 hours, weighed

and then immersed in clear water for a period of 24 hours and again weighed, the gain in weight is not to be more than 3½ per cent for pine blocks and 4½ per cent for gum blocks."

This test is made upon blocks as delivered for use in order that the effect of drying out after treatment may be included in the results.

d. The character of the oil with which the block has been treated is tested by extracting the oil with carbon bisulphide and then subjecting it to tests to determine whether it conforms to the specifications for oil to be used in the treatment. Fine turnings from the block are placed in an extraction apparatus with the solvent, and the oil completely extracted. The separation of the creosote oil from the solution is effected by distillation, the solvent being first removed at a temperature of about 120° C., and the creosote oil below about 370° C. The creosote oil thus separated is then subjected to tests to determine whether it meets the specification requirements.

e. It has been proposed to test the resistance to abrasion of the blocks by grinding them upon a disk machine, but no records are available as to results obtained in such tests, and they are of doubtful utility.

A standard method of making analyses of creosote has been adopted by the American Railway Maintenance of Way Association, and is now commonly employed in making such examinations.

ART. 78. CONSTRUCTION OF WOOD PAVEMENTS.

As stated in Art. 74 the older types of wood-block pavement, in which the blocks were laid with open joints on a plank foundation or on gravel, are prac-

tically obsolete, and wood blocks are usually laid with close joints upon concrete foundations. This gives firm support to the blocks and admits of even wear upon the surface of the pavement. A durable base also has the advantage that when the surface layer is worn out, the pavement may be resurfaced without removing the foundation. The concrete base is constructed in the ordinary manner as described in Art. 57. It is commonly about 6 inches thick, although under specially trying conditions a somewhat greater thickness is sometimes employed. In a few of the European pavements very heavy foundations, 7 or 8 inches thick, are employed; but these are exceptional and the 6 inch depth is usually found sufficient. Lighter foundations, 4 or 5 inches in depth may be used under favorable conditions and where traffic is not heavy; but these pavements are usually employed upon streets of considerable traffic, and in such situations very light construction is not desirable.

For the purpose of receiving the blocks and affording them uniform support, a cushion coat of sand or a thin coating of cement mortar is placed over the concrete. The sand cushion when used is usually about 1 inch in thickness and is placed in the same manner as in laying a brick pavement. When a mortar surface is employed, a coating of about ½ inch of mortar is floated over the surface of the concrete and brought to the exact form of the finished surface, the blocks being placed before the mortar sets and bedded into the surface of the mortar. This method, while used to a much less extent than the sand cushion, seems to give excellent results in maintaining a uniform surface where the work is properly done, giving more uniform support than the sand cushion.

The blocks are set with the grain vertical, close together and commonly in courses making an angle of 60 to 70 degrees with the curb line. In some instances the blocks are placed with open joints across the street of $\frac{1}{8}$ to $\frac{1}{4}$ inch. Most of the older work was constructed in this manner, the wide joints being intended to give better foothold to horses, as well as to allow for expansion. Expansion is commonly provided for by an expansion joint along the curb, although in some instances such joint is not used. These joints are filled with bituminous cement, and are usually about $\frac{3}{4}$ of an inch wide for streets not more than 50 feet in width. Sometimes expansion joints are used across the street at distances of about 100 feet apart, although the use of such joints is diminishing, and under ordinary circumstances do not seem to be necessary.

After the blocks are set, they are rolled with a small steam roller until the surface is smooth and even. When the blocks are placed on a mortar bed, the rolling must be completed before the mortar has set.

Filling the Joints. Three methods of filling joints are frequently employed, sand, pitch and cement mortar being used. Sand filler is applied by placing a light coating of dry sand over the surface and brushing it into the joints, then covering the pavement with a layer of sand and opening the street to traffic. Pitch joints are made by the use of asphalt or coal-tar paving cement as used for brick pavements. They are made by spreading the hot paving cement over the surface and brushing into the joints. Care must be used to apply the cement at such temperature as will cause it to readily run into the joints and brush off all surplus cement. A light coating of sand is then placed over the pavement to take up and grind off the pitch left on the surface of

the pavement, which may otherwise become objectionable in warm weather.

When the joints are grouted with hydraulic cement, a mortar composed of one part cement to two parts sand is usually employed, mixed to a liquid condition so that it may easily run into the joints. This mortar is slushed upon the surface and broomed into the joints, and a light coating of sand is placed over the surface before opening to traffic. This sand is ground by the traffic into the blocks, tending to make the surface more gritty.

Following are extracts from specifications recommended by a Committee of the American Society of Municipal Improvements in 1910:

"*Laying Blocks.* Upon the bed thus prepared the blocks shall be carefully set with the fiber of the wood vertical in straight parallel courses at right angles to the curb, except that one row of block shall be placed parallel with the curb and $\frac{3}{4}$ of an inch therefrom. The space thus formed between the curb and this row of blocks shall be filled with a bituminous filler having a penetration between 30 and 40 when tested at 77° F. On streets 50 feet or more in width, a second row of blocks parallel to the first row along the curb and $\frac{3}{4}$ of an inch therefrom, shall be laid and the space between the two rows filled with a bituminous filler as above, thus forming a double expansion joint.

"When deemed advisable by the engineer on streets for heavy traffic the row or rows of blocks parallel with the curb and the expansion joint may be dispensed with.

"The blocks should be laid by setting them loosely together on the cushion coat, but no joint shall be more than $\frac{1}{8}$ of an inch in width. Nothing but whole blocks shall be used, except in starting a course or in such other

cases as the city may direct, and in no case shall less than one-third of a block be used in breaking joints. Closures shall be carefully cut and trimmed by experienced men. The portions of the blocks used for closure must be free from check or other fracture, and the cut end must have surface perpendicular to the top of the block and cut to the proper angle to give a close, tight joint.

"After the blocks are placed, they shall be rolled by a small steam roller until the surface becomes smooth and is brought truly to the grade and contour of the finished pavement. When laid on a mortar bed, the rolling shall be completed before the mortar has set, and all mortar that has set before the blocks are in place and rolled, shall be discarded and replaced by fresh mortar.

"After the blocks have been thoroughly rolled, the joints between them shall be filled by sweeping with fine, clean, dry sand, all of which shall pass a ten-mesh sieve.

"After inspection by the proper city official, the surface of the wood block pavement shall be covered to a depth of about ½ inch with fine screened sand. This sand is to be left upon the pavement for such time as may be directed by the proper city official, after which it shall be swept up and taken away by the contractor."

ART. 79. MAINTENANCE OF WOOD PAVEMENTS.

The ordinary maintenance of wood pavements, like that of most other pavements, consists in keeping the pavement clean and in repairing from time to time any small breaks that may appear in the surface due to imperfect material or to the settling of the foundation. These repairs would, of course, include the removal of any defective blocks and the taking up and replacing of

any portion which may settle out of surface through inefficient support.

It is generally agreed that the wear of a wood surface is improved by giving it an occasional coating of small gravel, in some cases two or three times a year, and permitting it to be ground into the surface for a few days.

When the wood pavement needs renewal or extensive repairs the surface may be relaid as with any other block pavement: if a permanent foundation be employed, by stripping the blocks from the foundation and placing a new surface in the same manner as the first one; with a board foundation that also must be relaid. Observations made by Mr. Kummer* seem to indicate that the continual wetting of a wood block surface tends to materially reduce the resistance to wear. Blocks from a street which had been sprinkled "instead of being pounded down and dense and hard, as is the case on streets not so sprinkled, had broomed out under the action of travel and the preservative material mechanically pounded out of the wood by the combined action of the travel and water. This, of course, leaves the surface of the block unprotected by the antiseptic preservative and subject to decay. It also, in its spongy condition, offers poor resistance to wear." The surface of wood block pavement does not give off fine dust, and need only be sprinkled sufficiently to be swept clean. For the best results it is necessary that the surface should be kept free from dirt.

* Engineering Record, August 25, 1906.

CHAPTER XI.

STONE-BLOCK PAVEMENTS.

ART. 80. STONE FOR PAVEMENTS.

STONE-BLOCK pavements are commonly employed where the traffic is heavy and a material needed which will resist well under wear.

Stone for this purpose must possess sufficient hardness to resist the abrasive action of wheels. It must be tough, in order that it may not be broken by shocks. It should be impervious to moisture and capable of resisting the destructive agencies of the atmosphere and of weather changes.

Experience only can determine the availability of any particular stone for this use. The stone may be tested in the same manner as brick, and perhaps something predicated as to the probability of its wearing well under traffic; but the conditions of the use of the material in the pavement are quite different from those under which it may be tested, and any tests looking to a determination of its weathering properties are apt to be misleading.

Examination of a stone as to its structure, the closeness of grain, homogeneity, etc., may assist in forming an idea of its nature and value for wear. Observations of any surfaces which may have been exposed for a considerable time to the weather, either in structures or in the quarry, will be the most efficient method of forming an opinion concerning the weathering proper-

ties of the stone. The conditions of use in pavements are, however, somewhat different from ordinary exposure in structures, on account of the material in the pavement being subject to the action of water containing acids and organic substances due to excretal and refuse matter. A low degree of permeability usually indicates that a material will not be greatly affected by these influences and also that the effect of frost will not be great.

Granite and sandstones are commonly employed for paving blocks and furnish the best material. Limestones are sometimes used, but have seldom been found satisfactory. Trap-rock and the harder granites, while answering well the requirements as to durability and resistance to wear, are objectionable on account of their tendency to wear smooth and become slippery and dangerous to horses. Granite or syenite of a tough, homogeneous nature is probably the best material for the construction of a durable pavement for heavy traffic. Granites of a quartzy nature are usually brittle and do not resist well under the blows of horses' feet or the impact of vehicles on a rough surface. Those containing a high percentage of feldspar are likely to be affected by atmospheric agencies, while those in which mica predominates wear rapidly on account of their laminated structure.

Sandstones of a close-grained, compact nature often give very satisfactory results under heavy wear. They are less hard than granite and wear more rapidly, but do not become so smooth and slippery, and commonly form a pavement that is more satisfactory from the point of view of the user. Sandstones differ very widely in character, their value depending chiefly upon the nature of the cementing material which holds them

together. In order that a stone may wear well and evenly in a pavement it is desirable that it be fine-grained, dense and homogeneous, as well as cemented by a material which is not brittle and is nearly impervious to moisture. Those sandstones in which the cementing material is of an argillaceous or calcareous nature are apt to be perishable when exposed to the weather. The Medina sandstones of Western New York and Ohio have been quite extensively used for paving purposes and prove a very satisfactory material for such use.

Limestone has not usually been successful in use for the construction of block pavements on account of its lack of durability against atmospheric influences. The action of frost commonly causes weakness and shivering, which produces uneven and destructive wear under traffic. There are, however, as wide variations in the characteristics of limestones as in those of sandstones, and there may be possible exceptions to the rule that, in general, limestone is not a desirable material for block pavement.

ART. 81. COBBLESTONE PAVEMENTS.

Cobblestones have in the past been quite extensively used in the construction of street pavements, although at the present time they have been for the most part abandoned. They are not usually durable pavements as the stones are easily loosened from their positions, although the stones themselves may be practically indestructible and used again and again in reconstructing the surface.

Cobblestone pavements as commonly constructed are also objectionable because they are permeable to

water and difficult to clean. They therefore collect, and become saturated with, the filth of the street and are very liable to injury from frost. They are also extremely rough and unsatisfactory in use for travel.

For paving the side-gutters, where broken stone or sometimes where wood is used for the traveled portion of the street, cobblestones may often be convenient and useful, and form a cheap and satisfactory means of disposing of surface drainage. Such an arrangement is shown in Fig. 33 (p. 365).

Cobblestones as used for pavements are usually rounded pebbles from 3 to 8 inches in diameter. They are set on end in a layer of sand or gravel, rammed into place until firmly held in position, and then covered with sand or fine gravel and left to the action of travel, which soon works the upper layer of sand into the interstices between the stones.

ART. 82. BELGIAN BLOCKS.

Belgian block is the name commonly applied to a pavement formed of nearly cubical blocks of hard rock. In the vicinity of New York this pavement has been largely used, the material being trap-rock from the valley of the lower Hudson. The blocks are usually from 5 to 7 inches upon the edges, with nearly parallel faces, and as commonly laid are placed upon a foundation layer of sand or gravel about 6 inches thick. This shape of block is objectionable on account of the width between joints being too great to afford good foothold to horses. The materials of which Belgian blocks have ordinarily been formed are very hard and (as already noted in Art. 81) wear smooth in service, becoming

slippery and thus increasing the effect of the too wide block. It is also better to have the length of the blocks somewhat greater across the street and let them break joints in that direction in order that they may give greater resistance to displacement under passing wheel-loads.

The older pavements of this character were usually placed upon a sand foundation. More recently this practice has, in the better class of work, been superseded by a more solid construction, a concrete base being used.

These pavements are now very little used, having given place to granite or sandstone blocks.

ART. 83. GRANITE AND SANDSTONE BLOCKS.

For the construction of the better class of stone-block pavements, blocks of tough granite or sandstone are used, set, in the best work, upon a concrete base, although sometimes placed upon a foundation of sand or gravel.

These pavements when well constructed are about the most satisfactory means yet devised for providing for very heavy traffic, as they present a maximum resistance to wear with a fairly good foothold for horses, and are much more agreeable in service than the old form of rough pavements. There is still much to be desired in the attainment of smoothness and absence of noise, and, as a general thing, it may be said that pavements of this kind are desirable only where the weight of traffic is so great that the smoother pavements would not offer sufficient resistance to wear. Even in such cases it may frequently be questionable whether an additional expense for maintaining a pave-

ment which would be more pleasant in use and less objectionable to occupants of adjoining premises would not be advisable from an economical as well as from an æsthetic point of view.

Blocks for stone pavements, in the best work, are cut in the form of parallelopipeds, 9 to 12 inches long, 3 inches wide, and 6 or 7 inches deep. The length should be sufficient to permit the blocks to break joints across the street. The width should be less than that of a horse's hoof in order that the joints in the direction of travel may be close enough together to prevent a horse from slipping in getting a foothold. The depth should be sufficient to give a bearing surface in the joints large enough to prevent the blocks from tipping when the load comes upon one end of them.

Specifications for granite blocks in New York City in 1908 are as follows:

"The blocks to be used shall be of a durable, sound and uniform quality of granite, each stone measuring not less than eight (8) inches, nor more than twelve (12) inches in length; not less than three and one-half ($3\frac{1}{2}$) nor more than four and one-half ($4\frac{1}{2}$) inches in width, and not less than seven (7) nor more than eight (8) inches in depth, and the stones shall be of the same quality as to hardness, color and grain. No outcrop, soft, brittle or laminated stone will be accepted. The blocks are to be rectangular on top and sides, uniform in thickness, to lay closely, and with fair and true surfaces, free from bunches. Over special constructions, the blocks may be of dimensions other than above specified when approved by the Engineer. The stone from each quarry shall be piled and laid separately in different sections of the work, and in no case shall the stones from different quarries be mixed."

ART. 84. CONSTRUCTION OF STONE-BLOCK PAVEMENTS.

Stone-block pavement for durable and effective service should be placed upon very firm foundations. Bases of concrete are usually employed and give the best results. These foundations are formed as described in Art. 57. and consist of a layer of concrete 4 to 8 inches thick, 6 inches being the most common depth.

In constructing the pavement, a cushion coat of sand, usually 1 to 2 inches thick, is spread upon the base of concrete for the purpose of allowing the bases of the paving blocks to be firmly bedded when the tops are brought to an even surface, the sand readily adjusting itself so as to fill all the spaces beneath the blocks and to offer a uniform resistance to downward motion in every part of the pavement, and in like manner transmitting the loads which come upon the pavement to the foundation so as to evenly distribute them over the surface of the concrete. The sand used for this purpose should be clean and dry, and all large particles sifted out, as they may prevent the blocks adjusting themselves properly. A thin layer of asphaltic cement is sometimes used in place of the sand with very good results.

The blocks should be laid as close together as possible in order to make the joints small. They are laid, like brick, with the longest dimension across the street, and arranged in courses transverse to the street, with the stone in consecutive courses breaking joints.

After the blocks are placed they are well rammed to a firm unyielding bearing and an even surface. Stones that sink too low under the ramming must be taken out and raised by putting more sand underneath.

As in the case of other block pavements, those of stone should be made as impervious to moisture as possible. The foundation should be kept dry, and moisture prevented from penetrating beneath the blocks where it has a tendency to cause unequal settlement under loads or disruptions under the action of frost. In the better class of work, therefore, the joints are filled with an impervious material which cements the blocks together. Asphalt or coal-tar paving cement is commonly employed for this purpose, as with brick and wood, and seems the most satisfactory in use, although hydraulic cement mortar is sometimes used. The coal-tar cement is commonly made by mixing coal-tar pitch with gas-tar and oil of creosote, a proportion sometimes employed being 100 pounds pitch, 4 gallons tar, and 1 gallon creosote.

The use of cement between the blocks binds them together and increases the strength of the pavement as well as the resistance of the blocks to being forced out of surface. It also deadens to some extent the noise from the passing of vehicles where asphaltic or coal-tar cement is used.

A method commonly used for filling the joints is to first fill them about one third full of small gravel, then pour in the paving cement until it stands above the gravel; then another third full of gravel, more cement as before; then gravel to a little below the top, and the joint filled full of cement; after which a coating of fine gravel is distributed over the surface.

Sometimes the joints are filled with gravel before the blocks are rammed to surface, and the paving cement afterward poured into the joints. This has the advantage of bringing the blocks to a very firm bearing, and secures complete filling of the joints.

Various modifications of the method above outlined are used in the principal cities for a pavement to withstand heaviest traffic and secure a maximum of durability; essentially it represents the best modern practice. The specifications used in New York City in 1908 contain the following requirements:

"29. On the concrete foundation, as designated, shall be laid a bed of clean, coarse, dry sand to such depth (in no case less than one and a half [1½] inches) as may be necessary to bring the surface of the pavement, when thoroughly rammed, to the proper grade.

"On this sand bed, and to the grade and crown specified, shall be laid the stone blocks at right angles to the line of the street or at such angle as may be directed. Each course of blocks shall be laid straight and regularly, with the end joints by a lap of at least three (3) inches, and in no case shall stone of different width be laid in the same course except on curbs. All joints shall be close joints except that when gravel filling is used, the joints between courses shall be not more than three-quarters (¾) of an inch in width.

"After the blocks are laid on a concrete foundation, they shall be covered with a clean, hard and dry gravel, which shall have been artificially heated and dried in proper appliances, placed in close proximity to the work, the gravel to be brushed in until all the joints are filled therewith to within three (3) inches of the top. The gravel must be washed white quartz and be entirely free from sand or dirt, and must have passed through a sieve of five-eighths (⅝) inch mesh and been retained by a three-eighths (⅜) inch mesh.

"The blocks must then be thoroughly rammed and the ramming repeated until they are brought to an unyielding bearing with a uniform surface, true to the

given grade and crown. No ramming shall be done within twenty (20) feet of the face of the work that is being laid.

"The boiling paving cement, heated to a temperature of 300° F. and of the composition hereinbefore described, shall then be poured into the joints until the same are full, and remain full to the top of the gravel. Hot gravel shall then be poured along the joints until they are full flush with the top of the blocks, when they shall again be poured with the paving cement till all voids are completely filled."

Art. 85. Stone Trackways.

In some of the European cities, particularly in Italy, stone trackways are sometimes employed on streets of heavy traffic for the purpose of diminishing traction. These trackways are formed of smooth blocks of stone

Fig. 27.

4 to 6 feet long, 18 to 24 inches wide, and 6 to 8 inches deep, laid flat and end to end so as to form a smooth surface upon which wheels may move with the least possible resistance. Between the tracks, and usually the remainder of the street, is commonly paved with cobble. The method of construction is shown in Fig. 27. The tracks drain to the middle, and the pavement between is made concave and provided with openings into the storm sewers for the escape of surface-water. The track and pavement are laid upon a layer of sand resting upon a broken-stone or gravel foundation.

Such trackways are quite durable under heavy traffic, and give light tractive resistance. They are not, however, desirable on the streets of towns where smooth pavements might be used, and are too expensive for use on country roads.

Steel trackways have frequently been proposed, and in a few instances have been tried, but have not been found successful and do not seem likely to become of any considerable importance.

CHAPTER XII.

CONCRETE PAVEMENTS.

ART. 86. CONCRETE AS SURFACE MATERIAL.

THE use of Portland cement concrete as material for the surfaces of street pavements has been in use in a small way since about 1895. Until after 1900, however, these pavements were very few in number and regarded as rather doubtful experiments. Since 1900 there has been a considerable increase in the use of this material, and quite a number of cities have tried it to some extent. Most of the work that has been done is of too recent date to show final results, or determine the best methods of construction. In several instances, the early pavements have given good wear under moderate traffic, but more experience is necessary to determine the extent to which these materials may meet the requirements of more general use, and to formulate methods of construction to secure the best results.

The objects in most instances of engineers who have constructed pavements of this kind have been to secure pavements for moderate or light traffic at less cost than brick, or other satisfactory pavements, could be constructed. Several methods of construction have been patented, and many, if not most, of the concrete pavements now in use have been constructed under some of these patents. These refer both to the composition of the cement mortar or concrete employed for surfacing the pavement, and to the method of construction.

Three types of construction have been used for pavements of this class:

(*a*) Mortar-surfaced pavements, in which a surfacing of mortar is applied to an ordinary concrete foundation before the concrete has set, in order that adhesion may develop between the mortar and concrete in setting.

(*b*) Monolithic concrete pavements, which consist of a single layer of concrete of the full thickness of the pavement.

(*c*) Grouted concrete pavements, constructed by first placing the coarse aggregate to the required thickness, and then pouring a grout of cement mortar over the surface, so as to fill the voids in the aggregate, which is rolled to a firm surface either before or after the grout is applied.

Concrete pavements seem to give promise of considerable development in the immediate future, and it is probable that their use will rapidly extend.

Art. 87. Portland Cement.

Portland cement is manufactured by burning a mixture of limestone and clay, shale or other argillaceous material; the mixture being accurately proportioned to give correct relations between the percentages of lime, silica and alumina in the resulting cement. The materials are finely ground, so as to obtain an intimate mixture, and the temperature of burning carefully regulated to secure proper chemical combinations. The clinker obtained from the burning of these materials is then finely ground into the powder which is used as cement.

The manufacture of Portland cement is very extensively carried on throughout the United States, and cement of high grade can be obtained with little difficulty

in nearly any locality. It is important that only first-class cement should be used in the construction of paved surfaces, and care should always be taken in the selection of the cement. The requirements of this service are very severe, and the soundness of the cement is of special importance. When it is not feasible to make tests of the cement, considerable reliance may be placed upon the selection of a good brand, but usually tests are imposed to insure proper quality.

The tests upon which dependence is placed to form judgment of the quality of cement are those for tensile strength, fineness and soundness. The standard methods of testing cement, which have been recommended by the American Society of Civil Engineers are now commonly employed, and standard specification requirements recommended by the American Society for Testing Materials are very generally followed. These requirements are as follows:

PORTLAND CEMENT.

"*Definition.* This term is applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3 per cent has been made subsequent to calcination.

SPECIFIC GRAVITY.

"The specific gravity of cement shall not be less than 3.10. Should the test of cement as received fall below this requirement, a second test may be made upon a sample ignited at a low red heat. The loss in weight of the ignited cement shall not exceed 4 per cent.

FINENESS.

"It shall leave by weight a residue of not more than 8 per cent on the No. 100, and not more than 25 per cent on the No. 200 sieve.

TIME OF SETTING.

"It shall not develop initial set in less than 30 minutes; and must develop hard set in not less than one hour, nor more than 10 hours.

TENSILE STRENGTH.

"The minimum requirements for tensile strength for briquettes one square inch in cross-section shall be as follows, and the cement shall show no retrogression in strength within the periods specified:

NEAT CEMENT.

Age.	Strength.
24 hours in moist air	175 lbs.
7 days (1 day in moist air, 6 days in water)	500 "
28 days (1 day in moist air, 27 days in water)	600 "

ONE PART CEMENT, THREE PARTS STANDARD OTTAWA SAND.

7 days (1 day in moist air, 6 days in water)	200 lbs.
28 days (1 day in moist air, 27 days in water)	275 "

CONSTANCY OF VOLUME.

"Pats of neat cement about 3 inches in diameter, ½ inch thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of 24 hours.

"(*a*) A pat is then kept in air at normal temperature and observed at intervals for at least 28 days.

"(*b*) Another pat is kept in water maintained as near 70° F. as practicable, and observed at intervals for at least 28 days.

"(*c*) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for 5 hours.

"These pats, to satisfactorily pass the requirements, shall remain firm and hard, and show no signs of distortion, checking cracking or disintegrating.

SULPHURIC ACID AND MAGNESIA.

"The cement shall not contain more than 1.75 per cent of anhydrous sulphuric acid (SO_3), nor more than 4 per cent of magnesia (MgO)."

Portland cement is sold packed in barrels, containing about 376 pounds of cement, or in canvas bags, each containing one-fourth barrel. For the purpose of proportioning mortar or concrete by volume a barrel is commonly taken as holding 3.8 cubic feet, or the cement is assumed to weigh about 100 pounds per cubic foot. Cement must always be stored in a dry place and carefully protected from moisture; it should not be piled in contact with the ground, and must be covered to exclude all water.

ART. 88. PORTLAND CEMENT MORTAR.

Portland cement mortar is formed by mixing Portland cement with a fine mineral aggregate, and wetting the mixture to a paste, which hardens with the setting of the cement. In the preparation of cement mortar, care must be used to insure that the cement and aggregate are thoroughly mixed and evenly distributed through the mortar. When mixing by hand, the dry materials should

be mixed to a uniform color before adding the water. The mortar must in all cases be placed in the work before beginning to set, and be left undisturbed until thoroughly set, and until it has acquired sufficient strength to resist distortion.

Fine Aggregate. The fine aggregate is either sand, stone screenings or other similar material, which will pass a screen of ¼-inch mesh. Sand for this use should be coarse or contain a considerable percentage of coarse grains (not passing a sieve of thirty meshes to the inch). It should be clean and free from loam, and other impurities, and should not contain more than from 3 per cent to 6 per cent of dust which will pass a sieve of 100 meshes to the inch.

In preparing mortar, good results require that the voids in the fine aggregate should be completely filled with cement, and the amount of cement used should be somewhat larger than the volume of voids to be filled. It is therefore desirable that the sizes of the particles of fine aggregate be graded so as to give a minimum of voids, and, in important work it is necessary to carefully examine the aggregate in this particular and proportion the mortar accordingly. The following tests for determining the voids in aggregates, recommended by a committee of the National Association of Cement Users, may be used with advantage for this purpose:

Test for Voids. To determine the voids in the coarse aggregate or fine aggregate: Prepare a vessel, the cubical contents of which is exactly one cubic foot (1728 cubic inches), being smaller at the top than at the bottom. Fill the vessel with the aggregate, thoroughly dried, 'coarse' or 'fine' as the case may be, which is to be used. Shake or jar the vessel containing the aggregate until it is compacted as thoroughly as possible and the vessel is

level full. Then ascertain the net weight of the fine aggregate in the vessel, deduct this weight from w (the weight of one foot cube of mineral of which the fine aggregate is composed) divide the difference thus obtained by w. The result is the percentage of voids.

When mortar surfaces are employed upon pavements, the fine aggregates are frequently composed of crushed granite screenings, or sometimes of special mixtures of granite and sand, or limestone, intended to give effective resistance to wear, or to render the paving surface gritty and prevent it being slippery. Some of these combinations of materials are patented. For the purpose of comparing the values of various fine aggregates for use in mortars, the Committee of the National Association of Cement Users recommends that they be tested in comparison with standard sand, as follows:

"Mortars composed of 1 part Portland cement and 3 parts fine aggregate by weight when made into briquettes should show a tensile strength of at least 70 per cent of the strength of 1:3 mortar of the same consistency made with the same cement and standard Ottawa sand. To avoid the removal of any coating on the grains which may affect the strength, bank sands should not be dried before being made into mortar, but should contain natural moisture. The percentage of moisture may be determined upon a separate sample for correcting weight of sand. From 10 to 40 per cent more water may be required in mixing bank or artificial sands than for standard Ottawa sand to produce the same consistency."

ART. 89. PORTLAND CEMENT CONCRETE.

Portland cement concrete consists of a mixture of Portland cement, or Portland cement mortar, with a

coarse aggregate (gravel, broken stone or similar material), the materials being so proportioned as that the mortar fills the voids in the coarse aggregate, and the cement those of the fine aggregate.

Coarse Aggregate. The coarse aggregate usually consists of gravel or crushed rock, all of which is retained by a sieve of $\frac{1}{4}$-inch meshes, and grading upwards to any size which may be readily handled in mixing and not too large to pack in the thickness of the concrete layer. The largest stones should not be greater in diameter than $\frac{2}{3}$ the depth of the concrete layer, and a grading of sizes is desirable, which will reduce the voids to be filled with mortar to a minimum. In some instances, the aggregate is screened into several sizes, and these mixed in such proportions as to give a minimum of voids.

When the concrete is to be used as surface material care should be taken to secure a uniform mixture, in order that the resistance to wear may be even. Some engineers specify nearly uniform sizes of rock on this account, using a larger proportion of mortar. Commonly, however, crusher-run rock is used, with only the fine parts and the pieces which are too large screened out, no grading of sizes being attempted on account of cost.

The material used for the coarse aggregate should be of hard and durable character. Gravels, limestones and trap rocks are commonly employed. For the monolithic pavement, where the concrete forms the wearing surface of the pavement, particular attention should be given to securing rock that will be resistant to wear. For such use, special mixtures of rock are sometimes made, two kinds of rocks of somewhat different wearing properties being used in fixed proportions. Some of these mixtures are patented. In general the choice of stone is limited by what may be available in the neigh-

borhood of the work, but careful consideration should always be given to the suitability of the material. When the concrete is for foundation only and not exposed upon the surface, a poorer grade of rock may be employed.

The Association for Standardizing Paving Specifications has suggested the following specification for concrete for use in pavements;

FINE AGGREGATE.

"The fine aggregate shall consist of any material of siliceous, granite or igneous origin, free from mica in excess of 5 per cent, and other impurities, uniformly graded, the particles ranging in size from $\frac{1}{4}$ inch down to that which will pass a No. 100 standard sieve.

COARSE AGGREGATE.

"The coarse aggregate shall be sound broken stone, trap rock, or granite having a specific gravity of not less than 2.6. It shall be free from all foreign matter, uniformly graded and shall range in size from $\frac{1}{4}$ inch up, the largest particles not to exceed in any dimension one-half the thickness of the concrete in place.

PROPORTIONS.

"In preparing the concrete the cement and aggregate shall be measured separately, and then mixed in such proportions that the resulting concrete shall contain fine aggregate amounting to one-half of the volume of the coarse aggregate, and that five cubic feet of concrete in place will contain ninety-four (94) pounds of cement.

MIXING.

"The ingredients of the concrete shall be thoroughly mixed, sufficient water being added to obtain the desired consistency, and the mixing continued until the materials are uniformly distributed and each particle of the fine aggregate is thoroughly coated with cement, and each particle of the coarse aggregate is thoroughly coated with mortar.

"Where a mechanical mixer is used, the materials must be proportioned dry, and then deposited in the mixer all at the same time. The mixer must produce a concrete of uniform consistency and color, with the stones thoroughly mixed with water, sand and cement.

CONSISTENCY.

"The materials shall be mixed wet enough to produce a concrete of a consistency that will flush readily under light tamping, but which can be handled without causing a separation of the coarse aggregate from the mortar.

RE-TEMPERING.

"Re-tempering, that is, re-mixing with additional water, mortar or concrete, that has partially hardened, will not be permitted."

ART. 90. MORTAR-SURFACED PAVEMENTS.

Most of the earlier concrete pavements are of this type. They consist of a concrete foundation, constructed in about the same manner as for a brick or asphalt surface, with a layer of carefully prepared cement mortar

to take the wear of the traffic. In many of the pavements, the method of construction is about the same as that used in placing cement sidewalks, the depth being usually somewhat greater, with a difference in finishing the surface to prevent slipperiness.

The fine aggregate used in making mortar for this purpose should be of hard material, capable of resisting abrasion. Crushed granite and trap rock have frequently been employed for the purpose, and mixtures of granite and limestone, or natural sand and crushed limestone, are sometimes used. Fairly good results have been obtained with all of these materials. These pavements are commonly from 5 to 7 inches in depth, with a surface layer 1½ or 2 inches thick. The mortar for the surface must always be placed before the foundation concrete has set in order to secure proper adhesion between the two.

In finishing the surfaces of these pavements, some method, intended to prevent the surface being too smooth and slippery, has usually been adopted. Sometimes the surface is cut into small blocks, tool cuts are made across the street a few inches apart, or the surface is pitted with a brass roller. In other instances, brushing the surface with a stiff broom has seemed to leave the surface in good condition for wear, while the use of aggregate composed of a mixture of two materials of somewhat different wearing qualities has been claimed to assist in preventing the pavement being slippery.

Expansion joints along the curb, or between the gutter and roadway proper, and also extending across the street at frequent intervals are needed to prevent the cracking of the pavement with the expansion and contraction of the pavement. These joints extend through the pavement and are usually filled with bituminous cement

filler, although creosoted wood blocks are being used to some extent for the transverse joints. In the earlier pavements expansion was taken care of by dividing the pavement into rectangular blocks, as in the construction of sidewalks, but it was found that the wear of the pavements was mainly due to the breaking down at these joints, and particularly the longitudinal joints, and later practice has for the most part abandoned all continuous longitudinal joints, except at the sides. A method of construction which has been somewhat extensively used for this type of pavement, is patented and is known as the Blome Granitoid Pavement. Specifications sometimes used in the construction of surface of this pavement are as follows:

MIXING AND LAYING OF CONCRETE AND FORMATION OF THE BLOME COMPANY GRANITOID BLOCKING.

The concrete and blocking hereinafter specified shall be constructed and manipulated according to the Blome Company patents and processes, using materials mixed in the proportions and laid as herinafter specified.

The pavement shall consist of 5¼ inches of concrete, and surface blocking 1¾ inches, making a total of 7 inches, exclusive of foundation.

After the sub-grade and foundation have been prepared as hereinbefore specified, there shall be deposited concrete composed of 1 part of Portland cement, 3 parts sand, and 4 parts of crushed limestone, trap rock, or clean gravel. These materials to comply with the requirements hereinbefore set forth and shall be mixed by special mixing machine suitable for the purpose to be approved by the engineer and shall be mixed at least five times before being removed from the mixer. The concrete

shall be thoroughly tamped in place, and shall be 5¼ inches thick, uniformly at all points, after having been compacted, shall be laid in sections with expansion joints, all as per the Blome Company patents and shall follow the slopes of the finished pavement so that the surface blocking is and shall be uniformly of the same thickness at all points.

Surfacing Material. After the concrete has been placed and before it has begun to set, there shall be immediately deposited thereon the Granitoid Blocking which shall be 1¾ inches in thickness to be composed of two parts of the hereinbefore specified Portland cement and three parts of clean, crushed granite, trap rock, hard stone, crushed gravel, crushed boulders, or other similarily hard materials shall be screened with all the dust removed therefrom, utilizing the following composition of this material.

Fifty per cent of the granite, trap rock, hard stone, crushed gravel, crushed boulders or other similarly hard materials to be what is known as ¼-inch size, 30 per cent of the ⅛-inch size, and 20 per cent of the $\frac{1}{16}$-inch size with all finer particles removed. These proportions of sizes are extremely essential and must be kept absolutely accurate as in this lies one of the essential requirements to produce proper results. This material to be mixed with cement thoroughly and after being wetted to a proper consistency and deposited on the concrete shall be worked into brick shapes of approximately 4½ inches by 9 inches with rectangular surface similar to paving blocks, all as per special method and utilizing grooving apparatus as employed under the Blome Company patents. The pavement shall be sloped in a manner as required by the city engineer.

Should there by any part or parts of this pavement

when completed where the slopes, contours, etc., have not been carried out in true manner then under this specification the contractor will be required to take up such part or parts down to the foundation and replace same to the proper level without expense of any kind to the city.

Expansion Joints. The contractor for the work above specified shall also be required to provide for expansion joints across the pavement at such locations as may be necessary, which expansion joints shall extend through the blocking and concrete and shall be filled with a composition especially prepared for the purpose according to the Blome Company patents. These expansion joints shall be constructed in an extremely careful manner under specific direction of the city engineer.

For the purpose of diminishing the wear at the expansion joints, a method of reinforcement has been devised and patented, which protects the corners of concrete at the joints. This protection may be applied to any concrete surface. A pavement is constructed by the owners of this patent, known as the Baker Armored Concrete Pavement, specifications for surface and joints of which are as follows:

WEARING SURFACE.

"After placing the above concrete base, and before it has taken its initial set, there shall be placed thereon a two (2) inch wearing surface of the following component parts:

"One (1) part of cement to one and one-half (1½) parts of clean, sharp sand, and three (3) parts of hard head pebbles of a uniform size to be not less than one-quarter (¼) inch in diameter, and not more than one-half (½)

inch in diameter. The proportion of sand to stone given is approximate as absorption tests may show the necessity of variation. Stone and sand to be screened and subjected to tests as described under paragraph No. 6 from time to time as the work progresses in order to insure a solid stone with all the voids completely filled with sand and cement.

ARMORED EXPANSION JOINT.

"Expansion joints one-half (½) inch wide shall be made wherever necessary to provide for expansion and contraction. Expansion joints to be filled with No. 6 pitch or other approved material. At intervals of twenty-five (25) feet, expansion joints will be provided extending from curb to curb.

"Where pavement comes in contact with street car or other tracks, expansion joints shall be made at the end of ties to provide for vibration caused by the jar of passing cars.

"All expansion joints are to be armored and sharp edges protected against abrasion by means of angles of ¼-inch steel plates, 3 inches wide, provided with shear members which tie them securely to concrete base and wearing surface. These are clamped to a dividing board shaped to conform to the crown of the street. After pavement has been finished, the dividing board must be removed, and opening covered with tar paper until filled with No. 6 paving pitch or other specified material.

"After the pavement has been finished for twenty-four (24) hours, it shall be covered with sand or shavings for a period of seven (7) days."

ART. 91. MONOLITHIC CONCRETE PAVEMENTS.

The construction of pavements of a single layer of concrete without the mortar surface seems to be to some extent superseding the mortar surface pavement, and to have given good results in a number of instances. It is claimed for this construction that the surface is not so apt to wear slippery, and that the larger aggregate offers greater resistance to wear than the mortar made of fine materials. The comparative value of the two methods in any particular case probably depends mainly upon the availability of suitable materials, and the cost of construction. The aggregate used in making concrete for this purpose should be hard, tough materials, capable of resisting abrasion. Hard limestones, granites, or trap-rock may be used, and the concrete must be very thoroughly and uniformly mixed, and must be placed and compacted before beginning to set. The proportions of the materials in the concrete should be such that all voids are thoroughly filled. A mixture of two grades of rock of different wearing qualities has sometimes been used for the purpose. A pavement, in which a mixture of limestone and granite is used, is patented, and known as the Moran Pavement.

In finishing the surface of a pavement of this type, the concrete is tamped until the mortar flushes to the surface, which may then be broomed to give a finish, or marked by tamping lightly upon planks laid transversely upon it. These surfaces are not commonly grooved, but expansion joints are used, as with the mortar-surfaced pavements. It is usually, the effect of contraction rather than that of expansion, which needs to be provided for in such work, and this contraction may be to some extent obviated by covering the surface with sand and keeping

it moist for a considerable time after placing the pavement.

The Association for Standardizing Paving Specifications have suggested the following method for placing a concrete pavement:

PLACING CONCRETE.

"The concrete shall be deposited in a layer on the sub-grade in such quantities that, after being thoroughly rammed in place, it will be of the required thickness, and the upper surface shall be true and uniform.

"In conveying the concrete from the place of mixing to the place of deposit, the operation must be conducted in such a manner that no mortar will be lost and the concrete must be so handled that it will be of uniform composition throughout, showing no excess or lack of mortar in any place.

THICKNESS.

"The thickness of the pavement shall be — inches, with its upper surface on the finished grade.

"The minimum thickness for concrete pavement shall be 5½ inches.

FINISHING.

"The pavement shall be finished by thorough hand tamping, until the mortar flushes freely to the surface, then lightly tamping with a template made of 2-inch plank shaped to conform to the curvature of the surface of the finished pavement and having a length of not less than one-half the width of the roadway to give a uniform surface with the slight markings thus made transverse to the street.

EXPANSION JOINTS.

"Expansion joints shall be placed at right angles to the curb line at intervals of 50 feet. These joints shall be not less than 1 inch wide and shall be filled with creosoted soft wood timber with the grain vertical and extending full depth of the pavement.

PROTECTION TO WORK.

"During the first four days after placing, the pavement shall be kept moist and it shall be protected against traffic until the concrete has thoroughly set. In no event shall the pavement be used within ten days after being laid."

ART. 92. GROUTED CONCRETE PAVEMENT.

Concrete pavements are sometimes constructed by placing a layer of broken stone upon the road-bed, rolling to a firm surface, and grouting with Portland cement grout, so as to fill the voids in the stone.

A pavement of this kind is patented and known as the Hassam Pavement. In the construction of these pavements, a grouting of 1 to 2 Portland cement mortar is used after the stone has been firmly compacted by rolling and the voids reduced to a minimum. The rolling is continuous during the process of grouting. Upon the surface so obtained, a thin layer of pea stone is spread, grouted and rolled until the grout flushes to the surface.

In constructing the Long Island Motor Parkway, a Hassam pavement was used, which was reinforced with wire fabric. In this case, a 2½-inch layer of stone was placed, the wire fabric laid upon this, and another layer of stone of the same depth added. The stone was then rolled and the pavement finished as usual, no expansion joints being used.

CHAPTER XIII.

CITY STREETS.

ART. 93. ARRANGEMENT OF CITY STREETS.

THE location of streets should be planned with a view to giving direct and easy communication between all parts of a city. The arrangement should also be such as to permit the subdivision of the area traversed by them in such a manner as to give the maximum of efficiency for business or residential purposes. The most obvious and satisfactory method of accomplishing these purposes is usually by the use of the rectangular system, with occasional diagonal streets along lines likely to be in the direction of considerable travel.

Streets so far as possible should be systematically arranged and continuous throughout the extent of the city, both to facilitate travel and to admit of their being so named and numbered that the locality of a place of business or residence may at once be evident, from its address, to any one familiar with the general plan of the city. The rectangular system is desirable on this account, and also because it furnishes blocks of the best form for subdivision into building lots.

The proper arrangement of streets will always necessarily depend in some measure upon the natural features of the locality, and any system of arrangement will be more or less modified by local topography. Where for topographic or æsthetic reasons it may be considered desirable to use curved lines for the streets,

the continuity and uniformity of arrangement should be maintained as far as possible. The use of curves on residence streets may sometimes be advantageous in reducing gradients or in its effect upon adjoining property through avoiding heavy earthwork. Where a change in direction is necessary the use of a curve usually gives a better appearance than an abrupt bend, unless the change can be effected at the intersection of a cross-street. Care is required, however, to prevent the local introduction of curvature disarranging the general plans and producing the chaotic condition due to an irregular use of short streets.

In laying out a rectangular system of streets the blocks ordinarily will preferably be long and narrow. The distance needed between streets in one direction is only that necessary to the proper depth of lots, while in the other direction the streets need only be close enough to provide convenient communication for the travel and traffic. A convenient method would be to lay out the main streets so as to form squares large enough to permit the introduction of an intermediate minor street through the blocks. These minor streets may then be introduced in the direction that seems advisable in each locality. Such an arrangement is shown in Fig. 28. The diagonal streets cut more space from the blocks traversed by them, but give more frontage and property fronting them will usually have more value than other property in its vicinity.

The proper location for diagonal streets intended as thoroughfares for traffic is naturally determined by the positions of the business centers or public buildings and parks, from which they may radiate in such manner as to bring the outlying portions of the city into the most direct communication possible.

A city cannot usually be laid out complete. Its formation is a matter of gradual growth and enlargement, and the end cannot be seen from the beginning. For this reason it is frequently necessary to undergo great expense in the larger cities in cutting new streets or in changing the positions or dimensions of existing old ones in built-up districts in order to relieve the crowded condition of the streets, which hampers business and renders travel difficult and unpleasant. Much of this difficulty might frequently be obviated if in

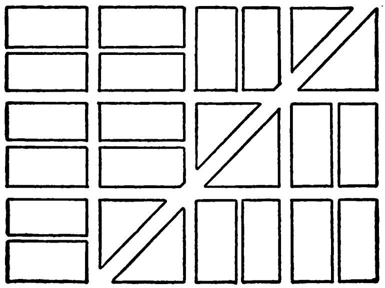

FIG. 28.

growing towns and cities proper attention were given to the regulation of suburban development. Such development should be under municipal control so far as to require at least that each new subdivision which opens new streets should be made with a view to affording proper ways of communication between adjoining properties by making streets continuous. Where such regulation does not exist streets will be laid in any manner to best develop the particular property in which they are placed.

A good example of the advantages of systematic and liberal plans in street arrangement, as well as of the

FIG. 29.

evils of unregulated extension, is given by the case of Washington, D. C.

Fig. 29 shows a portion of the city of Washington illustrating its systematic arrangement. It consists of a rectangular system, together with two sets of diagonal avenues, and open squares or circles at the intersections of the avenues.

Fig. 30 shows a number of suburban subdivisions on the borders of the city of Washington, made previous

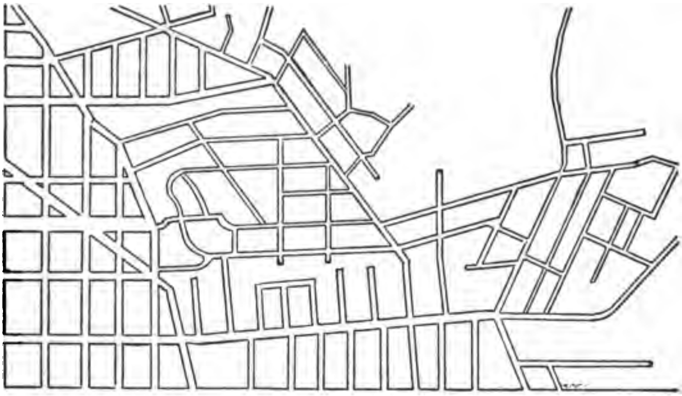

FIG. 30.

to the adoption of the law regulating them. In some cases the streets of adjoining subdivisions have no communication with each other, and the general tendency is toward a labyrinth of short streets. The law now requires that all street extension within the District of Columbia shall conform to the general plan of the city of Washington; and under the operation of this law the lines of many of the city streets have been extended to all parts of the District, and all of the suburban development is being gradually brought with

the city into one harmonious whole, on the same generous plan that exists within the city. The rectification of the irregular plats upon the borders of the city must, however, be a matter of heavy expense to the District.

ART. 94. WIDTH AND CROSS-SECTION.

The width of city streets is important both on account of its influence upon the ease with which traffic may be conducted, and because of its effect upon the health and comfort of the people, by determining the amount of light and air which may penetrate into thickly built-up districts.

To properly accommodate the traffic of commercial thoroughfares in business districts of towns of considerable size, it is desirable that a street should have a width of 100 to 160 feet, the whole of it to be used for roadway and sidewalks. Wide streets are especially needed where, as in the larger cities, they are bordered by high buildings or are to carry lines of street railway.

Residence streets in a town of considerable size, where houses are set out to the property line and stand close together, should have a width of at least 80 to 100 feet in order to look well and give plenty of light and air.

The streets in nearly all large towns are laid out too narrow; they are crowded and dingy. The chief difficulty is that the future of a street is not usually foreseen when it is located. Owners in subdividing property are only anxious to get as many lots as possible out of it, and there are usually no regulations looking to the future health and comfort of residents when the street shall be built upon. In the growth of a town the nature of localities changes; residence streets become

business streets, streets devoted to retail trade become wholesale streets, and mercantile districts are given up to manufacturing. If a city could be laid out complete from the beginning it would be comparatively easy to consider the requirements to be met and locate the streets accordingly. Under existing conditions this is not possible, but a more liberal policy in planning streets would usually be found of advantage in any growth that may ensue. There is also very frequently an immediate financial advantage in the enhancement of values due to wide streets. A lot 100 feet deep on a street 80 feet wide will nearly always be of greater value than if the same lot be 110 feet deep and the street only 60 feet in width.

In Washington, D. C., which probably has the best general system of any American city, no new street can be located less than 90 feet in width, and avenues must be at least 120 feet wide. Intermediate streets, called places, 60 feet wide, are allowed within blocks, but full-width streets must be located not more than 600 feet apart. The value of this liberal policy to the city of Washington is evident not only in the increased comfort of the people, but in its large growth as a residential city and the increased value of property in it.

While it is advantageous to have the street wide between building-lines, it is not necessary that the whole street width be used for pavements. The street pavement should be gauged in width by the immediate necessities of the traffic which is to pass over it. The pavement should be wide enough to easily accommodate the traffic, but any unnecessary width is a tax upon the community in the construction and maintenance of more pavement than should be required, and

perhaps diminishes the length of street which may be improved with available funds. Thus, for a residence street in general a width of 30 to 35 feet between curbs is usually ample, with a foot-walk upon each side 5 to 10 feet wide. The remainder of the street width should be made into lawns upon each side, with tree spaces between the sidewalk and roadway.

Fig. 31 shows in partial section the arrangement of a 90-foot residence street for moderate traffic. For residence streets of lesser importance, where the travel is light and the street is only required to furnish facilities to meet the needs of its immediate locality, a less width of pavement may often be advantageously

FIG. 31.

used. A pavement 24 feet wide is sufficient to accommodate a very considerable amount of light driving, and in many places, especially in the smaller towns where funds for effective improvement are obtained with difficulty, even less widths may be employed with the result of improving the streets both in appearance and usefulness. All that is really needed in such cases is room for teams to pass comfortably and to turn without difficulty. The narrowing of roadways on streets of light traffic to what is really necessary may often make possible improvements which will turn a broad sea of mud into a narrow, hard roadway and a grass-plat. Fig. 32 shows the arrangement of a village street 50 feet wide for light service.

In many cases for village streets, where the traffic is light and it is essential that the cost of construction be

low, it may be good practice to construct the traveled portion of the roadway of macadam, or other pavement, and use cobble gutters at the sides without

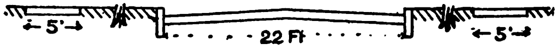

FIG. 32.

curbs. Fig. 33 shows a roadway 30 feet wide, with macadam middle and cobble gutters. In Saginaw, Mich., this method has been followed, using either macadam or wood blocks for the middle portion, and in the report of City Engineer Roberts for 1893 it is recommended as economical and efficient.

The cross-section of streets must be arranged with reference to proper surface drainage. The street is

FIG. 33.

given a crown at the middle to throw the water into the gutters, and sidewalks usually have a sufficient inclination toward the gutter to cause them to drain over the curb. The crown necessary to insure good drainage in the roadway depends upon the nature of the covering, being less as the surface is more smooth and less permeable to water. For macadam roadways, it may vary from about $\frac{1}{40}$ to $\frac{1}{60}$ of the width of the roadway. For the various pavements, the required crown varies from about $\frac{1}{60}$ to $\frac{1}{120}$ of the width, according to the smoothness of the surface and the permeability of the construction. For brick, asphalt, or wood-block surfaces, a crown of from $\frac{1}{80}$ to $\frac{1}{100}$ of

the width is commonly ample. Stone blocks may need slightly more; while, on streets of considerable longitudinal slope, the crown may be made somewhat lighter.

The form of section is usually a convex curve, sometimes circular but more often parabolic, the parabolic curve differing but slightly from the circular. This form is shown in Fig. 34. The distance of the

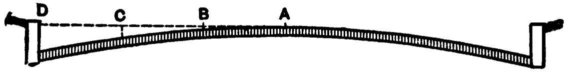

FIG. 34.

curved surface below the horizontal through the highest point is proportional to the square of the horizontal distance from the center. Thus, if the distance $A-D$ be divided into 3 equal parts, the vertical distance from B to the curve is one-ninth and from C four-ninths of that at D.

The street is usually made practically level across, the curbs and sidewalks at the two sides being given the

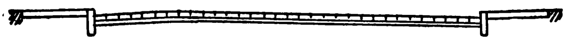

FIG. 35.

same elevation. The parking at the sides may have a slope between the sidewalk and the building-line when it is necessary or advantageous. Sometimes, on streets along a slope, expense may be saved or adjoining property benefited by placing the sidewalk at a different elevation from that of the street, as shown in Fig. 5, or by placing one curb lower than the other and moving the crown of the road to one side, as shown in Fig. 35.

The surface drainage of alleys is secured either by forming the section as in a street, with a crown at the middle and gutters and curbs at the sides, or, as is commonly preferable with narrow alleys, by placing the gutter at the middle and sloping the pavement from the sides to the center. Where the gutter is in the middle it is common to make the bottom of the gutter of a flagstone 15 to 18 inches wide. Fig. 36 shows a

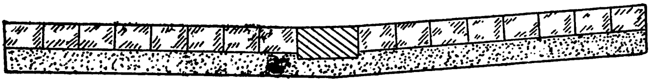

FIG. 36.

center-drained alley with block-stone pavement upon sand foundation.

The form shown in Fig. 36 is also usually employed where concrete pavement is used for alleys, as is quite common. This is desirable in many instances on account of the good drainage afforded, and the resistance of the material to dampness.

Fig. 37 shows a side-drained cobble pavement for an

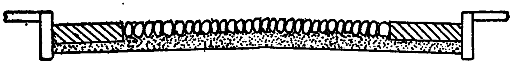

FIG. 37.

alley. These have been extensively used in the past, being usually placed upon sand foundation. They are gradually being replaced by brick or concrete pavements.

ART. 95. STREET GRADES.

The grades of city streets necessarily depend mainly upon the topography of the site. Wherever possible,

it is desirable that grades be uniform between cross-streets.

In establishing grades for new streets through unimproved property, they may usually be laid with reference only to obtaining the most desirable gradients for the street within a proper limit of cost. But where improvements have already been made, and located with reference to the natural surface of the ground, it is frequently a matter of extreme difficulty to give a desirable grade to the streets without injury to adjoining properties. In such cases it becomes a question of how far individual interests shall be sacrificed to the general good. It may be said in this connection that adjustments to new grades are usually accomplished much more easily than would be anticipated, and when accomplished the possession of a desirable grade is of very considerable value to adjoining property. Too great timidity should not, therefore, be felt in regard to making necessary changes because of the fear of injuring property in the locality.

Where a grade if made continuous between intersecting streets would be nearly level, it is frequently necessary to put a summit in the middle of the block and give a light gradient downward in each direction to the cross streets in order to provide for surface drainage. The amount of slope necessary to provide for proper drainage depends upon the character of the surface and smoothness of the gutter. For a surface of earth or macadam the slope should not be less than about 1 in 100, and for paved streets from 1 in 200 to 1 in 250.

In some cases it may be possible to give sufficient slope to gutters to carry off the surface-water by making the gutter deeper at the ends than in the middle of the block without making a summit in the crown of

the street. The curb in such case would be made level or of uniform gradient.

It may frequently be necessary to consider the effect of grade in determining the character of pavement to be employed upon a street. Asphalt is commonly limited to grades of 4 or 5 per cent, although some engineers use it on 6 or 7 per cent grades. Brick is commonly used on grades up to about 8 per cent, and in some places has given satisfactory service on 10 per cent grades. Wide joints, about ½ inch, are sometimes used in brick pavements on steep streets, in order to afford a better foothold for horses. This, however, in other instances appears to be unnecessary, provided the pavement is kept clean and in good condition.

Wood blocks may safely be used on grades of 5 or 6 per cent, while smooth stone blocks are employed in about the same manner as bricks, being if anything a little more slippery than bricks. Stone blocks of somewhat rough character are successfully used in some instances on grades of 12 or 13 per cent.

In a report on the streets of Duluth in 1890, Messrs. Rudolph Hering and Andrew Rosewater recommend for steep streets, in addition to the above, that brick may be used in which the tops are rounded, and that wood blocks for such use have their upper edges chamfered on each side, or if round blocks be used, around the blocks. Subsequent experience has, however, seemed to indicate that, except in extreme cases, such special construction is not necessary.

On the streets too steep for smooth pavement it is not unusual to pave part of the street width with a smooth pavement, like asphalt, and the remainder with stone blocks or some rough pavement for use in slippery weather.

ART. 96. STREET INTERSECTIONS.

At intersections the crown of the roadway pavement on each street should, if possible, be continuous to the center of intersection, in order to prevent vehicles on one street from being subjected to the jar incident to passing over the gutter of the other. Where a storm-sewer is available into which the water from the gutters on the upper side can be emptied this is a simple matter, but where such sewers do not exist it requires the adoption of some special means of draining the gutters on the upper side. This may sometimes be accomplished by a culvert across the street, the gutters being somewhat depressed at the corners to bring the channel sufficiently low. In other cases, where the slope is sufficient, it is more satisfactory to construct an underground pipe-drain from the upper corner to some point in the gutter below the crossing.

Where the rate of grade is such that it is feasible, it is desirable that the grade of both streets should be brought to a level at intersections. The top of the curb at the four corners should be at the same elevation, thus permitting the continuation of the full section of each roadway until they intersect. It is also desirable that the sidewalks at the corners be level; that is, the points *a a* in Fig. 38 should all be placed at the same elevation, which will make the entire street section, including sidewalks, horizontal across the direction of travel on each street.

On very steep slopes it may not be possible to flatten out the grade to a level in crossing transverse streets, and in such cases the elevations require study, and need to be carefully worked out for each particular case. In the report of Messrs. Rudolph Hering and Andrew

Rosewater upon the streets of Duluth, it is recommended that in all cases the grade shall be reduced to 3 per cent between the curb lines of cross streets, and the grade of the curb reduced in all cases to 8 per cent for the width of the sidewalks of intersecting streets. This is to be considered the maximum allowable rate of transverse grade, and only to be employed in case of necessity. If in Fig. 38 the arrow represents the direction of steep slope, and the street transverse to that direction has a roadway 40 feet wide with sidewalks

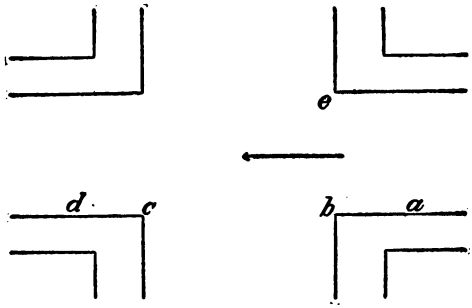

FIG. 38.

10 feet wide, the above limits would permit the curb at *c* to be 1.2 feet lower than that at *b*, and admit of a fall of 0.8 foot in the curb line from *a* to *b* and from *c* to *d*. If both streets have the same grade and width the curb at the lowest corner would be 2.4 feet lower than at the highest corner.

Sometimes, where the parallel streets in one direction follow the lines of greatest slope, and the cross streets are normal to them, the proper grades at intersections may be arranged by giving the streets along the slope a section similar to that shown in Fig. 32 throughout its length, thus permitting the street in the direction

of slope to continue its grade across the intersection without altering at that point the side slope of the cross street.

For a case of maximum slope this would make the section of the roadway of the cross street a plane surface sloping uniformly from the upper to the lower curb, or in Fig. 35 it would transfer the street crown to the upper curb.

ART. 97. FOOTWAYS.

Footways are not required to bear the heavy loads which come upon the roadway pavement, but in streets of considerable travel are subjected to a continual abrading action, and for good service are required to be of a material which will resist abrasion well, of so uniform a texture as to wear evenly, and not hard enough to become smooth and slippery in use.

A good sidewalk should always present an even surface, and therefore requires a firm foundation to resist the displacement of the blocks of which it may be composed. It must also be durable under atmospheric changes, and of material that may be easily cleaned. The materials commonly employed are gravel, wood, brick, asphalt, stone, and concrete.

Gravel walks are the cheapest of footways where suitable material is available. They are constructed in a manner similar to that used for gravel roadways, and require that the bed of the walk be well drained, and that it be well compacted by rolling or ramming before the walk is placed upon it. The best gravel walks are usually built upon a base of rough stone. This base may be 6 or 8 inches thick, and forms a solid founda tion upon which the gravel surface may be placed and

sustained against settling. Walks constructed in this manner are frequently used in city parks where the travel is considerable. On suburban roads gravel walks usually consist of a thin surface of gravel laid upon the earth-bed, and are replaced by some other surface when a more expensive construction can be afforded. Gutters are frequently necessary to protect the walk from the wash of surface-water, which otherwise very quickly destroys it.

Wood is commonly used for walks in the form of planks which are laid on stringers, the planks being placed perpendicularly to the direction of travel. It is comparatively short-lived, and requires considerable expenditure for repairs, as the material is perishable and also wears rapidly.

Brick footway pavements have been extensively used for many years, and form, when well constructed, a very durable and satisfactory sidewalk. As commonly constructed they consist of ordinary hard-burned bricks laid flat upon a layer of sand over the earth-bed. For light travel, pavements so constructed may last well and give good service; but they are apt to soon become uneven through the sinking of the bricks because of insufficient foundation.

In constructing such a pavement the sand layer should be well compacted by rolling or ramming before setting the bricks, which should also be rammed to a firm and even bearing. To give satisfactory results a foundation of sand and gravel or broken stone should be formed 8 to 10 inches in thickness. In Washington a layer of gravel 4 inches thick and well compacted is used, with a layer of sand of the same thickness upon it to receive the surface. In forming the pavements, the bricks are laid flat and as close as

possible. The joints are filled with sand, usually by coating the surface with a layer of sand before ramming and after completion a second coating, which is allowed to remain a few days after admitting the travel to it.

Care must be used in selecting brick for this purpose to get only hard-burned brick of uniform quality, in order that the resistance to wear may be even. The use of vitrified paving brick, as used for roadway pavement, would be of advantage on walks subjected to heavy wear.

The use of a concrete foundation and setting the brick on edge and in mortar, after the manner of constructing a roadway pavement, makes a very durable sidewalk under heavy travel. It is, however, somewhat expensive, and usually a stone surface would be preferable where such expense is to be incurred.

Footway pavements of a concrete in which coal-tar is the binding material have been widely used, but have not usually been satisfactory in use. As commonly constructed they wear rapidly and soften, becoming very disagreeable in hot weather. Some pavements of this character have, however, shown fairly good service.

Numerous methods have been proposed and tried for the construction of tar footwalks, differing from each other in the materials mixed with the tar to form the concrete, and in the manipulation of the process. Ashes mixed with sand and gravel are usually employed, and sometimes clinkers from an iron foundry. A somewhat successful pavement of this class has a small amount of Portland cement mixed with the ashes and sand used in forming the concrete before the addition of the tar.

Asphalt footway pavements are formed either of asphalt blocks or of a surface of sheet asphalt. Where blocks are used they are laid in the same manner as brick upon a foundation of sand or gravel. The blocks, or tiles as they are commonly called, are usually made flat, about 8 inches square and 2 to 2½ inches thick. They are laid with their edges either at right angles to the street line or at an angle of 45° with the street line — usually at right angles, on account of greater ease in laying.

Sheet-asphalt footways are laid in the same manner as an asphalt street pavement, the pavement, however, being given a less thickness. In Washington, D. C., these pavements are made about 3 inches thick, and constructed upon a bituminous base. Material removed from street pavements in re-surfacing is used for forming the surface material of the footway.

In Europe rock asphalt is frequently used for footways. Asphalt mastic is commonly employed, mixed with sand or gravel to give a wearing surface. The ingredients are heated together and applied hot to a broken-stone or concrete foundation. In Europe hydraulic cement concrete is used for the base, as in the driveways. A layer of 3 or 4 inches of concrete is employed, with a surface layer of rock asphalt or asphalt mastic and sand, ½ to ¾ inch in thickness for ordinary work.

Natural stone for footwalks is ordinarily used in the form of flagging. Where flagstones of proper size and good wearing qualities may be readily obtained, this kind of pavement, if well laid, makes a durable and satisfactory footwalk. Flagstones should be set upon a solid foundation and be firmly bedded so as to preserve an even surface. They should not be laid, as

is common in many places, directly upon an earth-bed but should have a cushion layer of sand or of some porous material to prevent unequal settling under the action of frost.

CONCRETE SIDEWALKS.

Concrete pavements, when well constructed of good materials, make the most satisfactory of foot-ways. They form an even surface, quite agreeable in service, and are durable and economical where exposed to considerable travel.

In the construction of a concrete sidewalk a base of cinders is usually employed, supporting a layer of rather meager concrete and a thin surface layer of cement mortar. The cinders are commonly 4 to 8 inches thick, 6 inches being ample for most walks, and 4 inches being sufficient for walks in residence districts of small travel, where the soil is firm. Care should be taken to insure the proper drainage of the base, so that water may not remain in the soil immediately under the walk, or stand in the cinders. The cinders should be placed to proper depth and well tamped with the upper surface parallel to the finished top of the pavement.

The concrete base is usually 3 or 4 inches thick, and sometimes on streets of heavy traffic it is made 5 inches. The wearing coat is from ½ inch to 1 inch in thickness, depending upon the wear to which it is to be subjected. A concrete base 3½ inches thick, with a wearing surface ½ inch thick, makes a very satisfactory walk for residence streets carrying moderate travel.

The composition of the concrete base must depend largely upon the materials available in the locality. Either gravel or broken stone may be used, with or

without sand, according to the character of the materials. A mixture of one part Portland cement, three parts sand, and six parts broken stone is commonly used. When good limestone is available, a mixture of one part Portland cement to four parts broken stone, without sand, is found very satisfactory, the stone being broken to pass a one inch screen and with only the fine dust removed. When sand or gravel is used, it is important that it be clean, as any dirt is likely to work to the surface in tamping and prevent the proper adhesion of the surface layer. For the same reason, the concrete must not be mixed too wet, and it should be well compacted by ramming.

The wearing coat is composed of Portland cement mortar, one part cement to one or two parts sand or screenings. The amount of cement used should be sufficient to fill the voids in the sand but not greatly in excess, as the resistance to abrasion is lessened by excess of cement. The material for wearing coat should be either clean, hard sand, or screenings from the crushed stone. The screenings should have the very fine dust removed, and when from a good quality of rock are superior to most natural sands. The mortar is brought to a uniform surface by drawing a straight edge along the tops of the forms at the sides of the walk. The surface is then worked smooth and uniform with a float and finished with a plastering trowel.

Joints should be left at intervals of 4 or 5 feet to prevent irregular cracks through contraction of the concrete. These joints need not all extend through the base of the walk, but at intervals of 3 or 4 joints one should extend through. The surface of a concrete walk should have a transverse slope of about $\frac{1}{4}$ inch to 1 foot to provide for proper surface drainage. For

residence streets of moderate travel a width of four to six feet is commonly required. Four feet is inconveniently narrow unless the street is very little used, while six feet is sufficient for a very considerable amount of travel.

ART. 98. CURBS AND GUTTERS.

Curbs are usually set in the streets of towns at the sides of roadway pavements for the purpose of sustaining and protecting the sidewalk or tree space, and of forming the side of the gutter. They are commonly formed of natural stone or concrete, but sometimes clay blocks are used.

STONE CURBS.

The curbs used in different places vary considerably in form and dimensions. Stone curbs vary from 4 to 12 inches in width and from 8 to 24 inches in depth. They are usually employed from 3 to 6 feet in length and set with close joints.

The depth must be sufficient to admit of their being firmly bedded, and to prevent overturning into the gutter. The front of the curb should be hammer-dressed to a depth greater than its exposure above the gutter, and the back deep enough to permit the sidewalk pavement to fit close against it where the sidewalk adjoins the curb. The ends of the blocks should also be dressed to the depth of exposure, and the part below the ground trimmed off so as to permit the dressed ends to come in contact when laid.

Granite is usually considered the best material for curbs, although both sandstones and limestones are used in many places. In the vicinity of New York the

North River bluestone has proved a good material for the purpose.

There are various ways of setting the curb. The object should be to bed it firmly on a solid foundation.

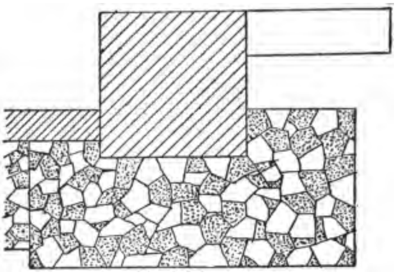

FIG. 39.

The best method is to place a bed of concrete under it. This construction is shown in Fig. 39, which represents the method used in setting granite curb in Washington, D. C. The curb is held firmly in place by the concrete foundation, which joins it rigidly to the roadway pavement.

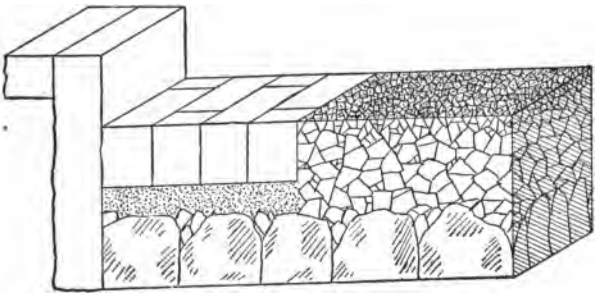

FIG. 40.

Where the concrete foundation is not used under

the curb a deeper curbstone is necessary, usually from 18 to 24 inches in good work. Curbs are very commonly set in the natural ground, the pavement coming against it on one side; but it is usually found advantageous to lay them upon a bed of gravel or broken stone, with gravel filled in the trench about them. The ordinary method of setting curbs is shown in Fig. 40.

The Washington specifications for ordinary work require that a bed of gravel 4 inches deep be used under the curb, and that the trench be filled with gravel placed in layers 3 or 4 inches deep, each layer being thoroughly rammed before adding the next.

CONCRETE CURBS.

Concrete curbs are extensively used, and their use is rapidly increasing, particularly in those sections where suitable natural stone does not occur. These curbs consist of concrete built in place in plank forms, extending continuously along the street, occasional joints being introduced to prevent irregular cracking. The concrete is laid and surfaced in the same manner as in sidewalk work, all exposed faces being surfaced with mortar. For curbs upon streets of light travel concrete mixed in the same proportions as for sidewalks gives good service; but where the use is more severe, a richer mixture will afford more strength, and about one part cement, two parts sand, and four of broken stone are frequently employed.

The curb usually extends to the bottom of the base of the pavement, the concrete base joining the curb and holding it in place. For residence streets the curb is commonly 5 or 6 inches thick, while upon heavy traffic

streets it may be made 8 or 10 inches thick. Where the traffic is very severe, concrete curbs are frequently reinforced, or faced, with steel at the edges for greater resistance to shocks. Several forms of patented reinforcement are available for such use.

BURNED CLAY CURBS.

Burned clay curbs are sometimes employed in small towns where brick pavements are used. These are made in such small sizes and short lengths that they are difficult to set to good line and are easily displaced. They have not in general proved satisfactory.

Curbs at street corners and driveways are commonly laid upon curves. On ordinary residence streets curves of 4 to 6 feet radius are usually employed, while upon wide streets with considerable traffic curves of 8 to 12 feet radius are desirable. These are easily set for concrete curbing by having forms to fit the whole curve. For curves of 3 or 4 feet radius stone curbing may be cut in two pieces for a right-angled turn. With curves of larger radius more pieces must be used and the cutting and setting becomes more expensive.

GUTTERS.

Gutters are commonly formed of the same material as the roadway pavement, which is simply extended to the curb.

In streets paved with brick or granite blocks the gutter blocks are sometimes turned lengthwise of the street, as shown in Fig. 22, for the purpose of facilitating the flow of water in the gutter. As already pointed out, however, this has the effect of making a continuous

joint between the pavement and gutter, and its utility seems doubtful.

For streets paved with broken stone it is common to employ stone gutters, formed of cobblestones, of narrow flags laid lengthwise of the gutter, or sometimes of rectangular blocks. Such construction is shown in Fig. 40. On streets paved with wood these gutters may also be frequently employed with advantage, especially where for any reason the gutter is likely to be kept damp. In forming a cobble gutter the stones are usually set upon a layer of sand or gravel after the manner of forming a cobble pavement. They should be firmly bedded and form an even surface.

Cobble gutters are often used on village streets where no curbs are set, and in such locations, where but slight expense is admissible, they are quite satisfactory if properly constructed. This method of construction is illustrated in Fig. 33.

Sometimes in work of this kind a flagstone is used for the bottom of the gutter and the sides are formed of cobble. This is preferable as affording a more free channel for the flow of the surface drainage.

To obtain satisfactory results it is always necessary that the foundation be of sufficient depth and well compacted in order to prevent the surface becoming uneven by the stones being forced downward into the road-bed in wet weather or through the action of frost. A layer of 6 to 10 inches of gravel or sand is usually required.

Where flagstones are used to form the gutter, they should be 3 or 4 inches thick, 10 to 15 inches wide, as may be required, and about 3 feet long. Care is required in laying that they may have an even bed and be well supported by the foundation.

Gutters of bricks, or of stone blocks, are often used for streets upon which the roadway pavement is asphalt, on account of the liability of the asphalt being injured by dampness. In this case the gutter is constructed by setting the bricks or blocks with their greatest length along the street. They are placed upon a bed of concrete, the same as is used for the foundation under the asphalt surface, and the joints are filled with hydraulic cement mortar, as in constructing brick pavement.

CONCRETE GUTTERS.

Concrete gutters are quite commonly used on streets paved with macadam, and sometimes at the sides of asphalt streets. These are sometimes flat curved gutters, similar in form to the cobble gutter shown in Fig. 33, but more commonly they are used with concrete curbs as combined curb and gutter. These consist simply of the concrete curb with a concrete gutter 18 to 30 inches wide attached and built together in one piece. This is usually placed, like a sidewalk, upon a layer of cinders or gravel, and is constructed in the same manner, the gutter, upon streets of moderate traffic, being usually about 5 or 6 inches thick.

Where the street pavement is carefully laid flush with the gutter, this makes a very satisfactory gutter. Upon macadam streets considerable trouble is sometimes experienced in keeping the surface of the macadam up to the level of the gutter, and in many instances, unless considerable care is taken both in construction and maintenance, a second gutter forms in the surface of the macadam next to the concrete gutter. This is due to the difficulty of properly compacting the macadam next to the gutter, as well as to the greater wear

of the macadam and the effect of rain in washing it. To secure good results it is essential that the macadam be brought flush with the concrete gutter so that the water may readily pass into the gutter, and that it be well compacted so as to prevent subsequent settlement.

ART. 99. CROSSINGS.

On streets paved with a smooth hard surface which is easily cleaned, such as brick or asphalt, special footway crossings are not usually required or desirable, unless the foot travel be very considerable. On other pavements, however, which are apt to be rough to walk upon or muddy in bad weather, as upon stone, or macadam, footways of flagstones, brick, or concrete are commonly provided.

Stone crossings consist of flagstones about 10 or 12 inches wide laid in rows across the street, the rows being 6 or 8 inches apart and paved between with stone blocks set in the ordinary manner. The crossing-stones are 3 or 4 feet long, and at least 6 inches thick in order that they may not be broken by the traffic. They should be laid with close joints and firmly bedded upon the foundation.

Brick crossings are usually constructed in the same manner as brick street pavements, being laid upon concrete base and having joints filled with cement mortar. They should be slightly crowned, so as to raise the crossing a little above the general level of the street and facilitate keeping them clean. These crossings are sometimes laid as double layer brick pavements with sand filled joints, but in general the better grade of construction is but slightly more expensive and is much more durable in use.

Concrete street crossings are placed in the same manner as concrete sidewalks. They should, like brick crossings, have a crown to aid in keeping them clean. Crossings, and sidewalks across alley openings or driveways, need to be somewhat heavier than ordinary sidewalks and are usually about 6 inches thick. It is common to cut longitudinal V-shaped grooves, about ½ inch to 1 inch wide, ¼ to ½ inch deep, and 4 inches apart, in the surface of the walk to afford a foothold to horses in crossing it. These grooves may readily be formed by use of the tool used in finishing joints, and are of material benefit in preventing the slipping of horses.

At street intersections where the number of pedestrians is large it is desirable that the crossing be carried across on the level of the top of the curb without leaving a step at the gutter crossing. This may be accomplished by bridging over the gutter with a flagstone or iron plate, or by placing the outlets for surface drainage a few feet back from the corner and eliminating the gutter at the corner.

Art. 100. Street-Railway Track.

Track for street railways upon paved streets should be constructed with a view to offering as little obstruction to ordinary street traffic as possible, while permitting the ready operation of the railway. These two points are apt to conflict, as the interest of the railway company in the construction of track is rarely identical with that of the public use of the street.

Any street-car track is objectionable on a paved street, both on account of the increased wear caused to the pavement, and because it forms an obstruction

to the ordinary traffic of the street. It is, however, a necessary evil, being required for the convenience of the public, and its detrimental effects may often be greatly lessened by proper attention to the methods of construction employed. On smooth pavements properly constructed track should offer no obstruction to vehicles crossing it, and afford no channels in which the wheels of vehicles may run and which prevent wheels readily leaving the track.

This requires that the surface of the pavement be flush with the top of the rail, and that it be laid in close contact with the rail.

It is also important that the method of construction used in both track and pavement be firm and substantial to prevent unevenness due to the yielding of the track or settlement of the pavement.

Construction of Track. Methods of construction used for street railway tracks are extremely various and opinions differ widely concerning them. When the traffic of the railway and street is light it is generally conceded that the most economical method is that of placing the rails directly upon wooden cross-ties, as in the construction of steam roads. Where, however, the traffic is heavy the difficulty and expense of making repairs becomes great, and the railway companies commonly recognize the advantage of solid and permanent construction. Several methods have therefore been devised for securing firm support to the rails.

Fig. 41 shows the ordinary method of construction where a concrete base is employed for the pavement and the tie is embedded in the concrete. In this construction the track is surfaced up by ballasting in the usual manner under the ties with gravel or broken

stone, after which the concrete base is filled in between and perhaps over the ties. The depth of rail is sometimes made the same as the thickness of the upper layers of pavement, thus bringing the top of the tie

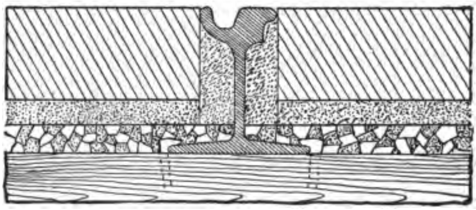

FIG. 41.

even with the surface of the concrete. Thus a six-inch rail may be used with a brick pavement having a two-inch sand cushion as shown in Fig. 42. If the depth of rail be less than this, stringers, as in Fig. 43,

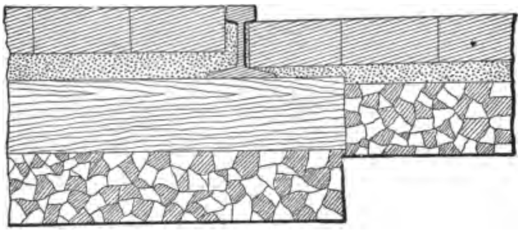

FIG. 42.

or chairs, as in Fig. 44, are necessary to raise the rails to the level of the paving surface. When stringers are employed they are usually connected by cast-iron braces to the cross-ties, and are also bedded and held in place by the concrete base of the pavement. The ties in such case are usually below the concrete. To secure greater stability when the rails are supported

by cross-ties a bed of concrete is sometimes placed under each tie and the track is tamped in concrete. This is shown in Figs. 42 and 44. In such construction it is usual to make a trench under the tie, fill this

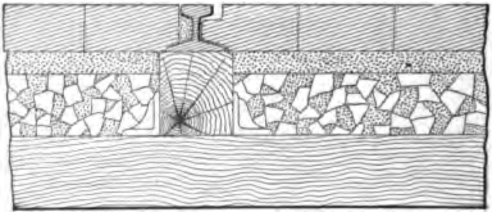

FIG. 43.

with concrete and tamp the tie with concrete, afterward placing the concrete base for the pavement between the ties.

On important lines in streets of heavy traffic repairs to track are often both difficult and expensive,

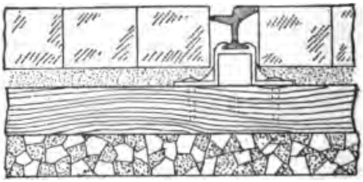

FIG. 44.

and very rigid and substantial construction is essential to an economical operation of the railway. To secure such construction the wooden ties are sometimes dispensed with and the rails placed directly upon the concrete. Several methods of construction of this character have been employed. Fig. 45 shows the simplest form, where the rails are placed directly upon

the concrete base of the pavement and spaced by iron tie-rods at intervals of six or eight feet. The concrete in this construction is usually made extra heavy in order to adequately support the rails and maintain them at the level of the pavement.

A more economical method of securing permanent

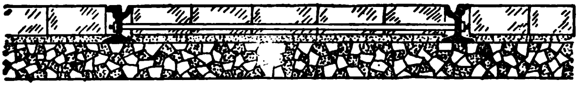

FIG. 45.

construction is by the use of a concrete beam or stringer under the rail. This method of construction is illustrated in Fig. 46. The concrete stringers are usually made of Portland-cement concrete from 9 to

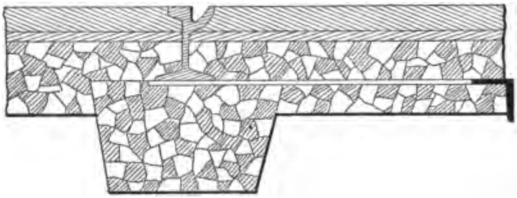

FIG. 46.

12 inches in depth and 12 to 18 inches in width The rails are commonly held in place by iron ties, to which the base of the rail is bolted, as shown in figure. Frequently light angle-bars are used for ties, but various other sections have also been employed for which special advantages are claimed. Spacing rods between the webs of the rails may also be employed as shown in Fig. 45, but these rods are objectionable in a block pavement on account of the difficulty of paving be-

tween them. The ties are usually spaced about ten feet apart.

In some instances, where concrete beams are used under the rails, ties are omitted altogether and the base of the rail is spiked directly to the concrete or bolted through the concrete beam to plates below. This latter method has been carried out at Rochester, N. Y., with entire success, no difficulty being experienced in holding the rails in position. In constructing such track the rails are usually laid on temporary wooden ties spaced ten or twelve feet apart and brought to line and grade, after which the concrete beams are placed and the wooden ties removed.

Form for Rails. The rails in common use for street-railway track are divided into two general classes: tee rails, as commonly used on steam roads, and girder rails, in which the head is so formed as to afford a channel for the flanges of the wheels and admit of the pavement being laid close against the rail on both sides.

Tee rails differ considerably in their details and weights and are often modified for street service by making them of greater depth than is usual for steam-road service. These rails are shown in Figs. 42 and 43. The upper surface varies from 2 to 3 inches in width and is usually made convex, the section being frequently circular, of radius 8 to 20 inches. As used for street railways, these rails vary from 4 to 7 inches in height. In using the smaller depths it is necessary, except for very thin paving surfaces, that the rails be supported on chairs or stringers to give room for paving over the cross-ties, and deeper sections are therefore more commonly used. The six-inch depth is frequently employed and is sufficient with an asphalt or

brick pavement, the ties, if used, being embedded in the concrete foundation.

The disadvantage of the tee rail consists in the fact that the pavement cannot come against the rail on the inside of the track, as it has no groove for the wheel-flange. The pavement must therefore either be lowered under the rail-flange or a groove be left between the head of the rail and the pavement. The first method, shown in Fig. 42, is ordinarily the best construction, as the pavement is set firmly against the rails and there are no exposed edges to cause rapid wear, but it is objectionable on account of the impact of wheels crossing in dropping from the rail, and because it tends to hold the wheels of vehicles in the track. The second method is accomplished by using a thin block or a filling of concrete under the head of the rail and paving against this filling, as is usual when stone-block pavement is employed between the rails, or when a toothing of stone blocks or bricks is employed with an asphalt pavement. For brick pavements special bricks are sometimes molded to fit against the rails, leaving a groove for the wheel-flanges, as shown in Fig. 43. Difficulty has sometimes been met in the use of these bricks on account of their tendency to tilt when the car-wheel flanges press down any dirt or small gravel which may fall into the groove, unless they are very firmly bedded next the rail. Tee-rail construction is very commonly preferred by railway companies, as giving a better road for operation. It affords cheap construction, has little tendency to become clogged with dirt, and will usually be avoided by the ordinary traffic of the street, not affording good channels for the wheels of vehicles.

Girder rails are divided as to form of head into

center-bearing, side-bearing, and grooved. They vary, as commonly used, from 6 to 9 inches in height, and each type is subject to several variations in form.

The *center-bearing rail* is shown in Fig. 47. It is the most objectionable of any of the forms in use, there being two channels, one on each side of the head, thus offering a double obstruction to traffic and causing greatly increased wear to the pavement. It is of advantage to the traffic of the railway because it does not retain dirt, and where streets are not kept in good condition cleanses itself, which is particularly important on electric roads in which the rail is used as a current conductor. Its objectionable features, however, prevent its use in most places.

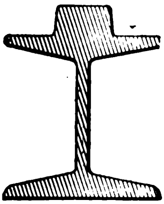

FIG. 47.

Side-bearing rails are shown in Figs. 44, 48, and 49. They are probably more commonly used than any other type of girder rail. The tram is from 2 to 3 inches wide and offers a smooth track for the wheels of vehicles, but it is difficult for a wheel to leave it and is extremely hard on the street traffic.

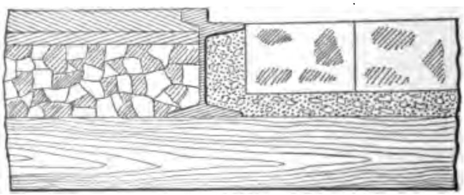

FIG. 48.

Pavements may be laid against the side-bearing rail as shown in Fig. 44, in which the surface of the pave; ment is at the same level inside as outside the track;

or, as shown in Fig. 48, in which the pavement inside the track is brought even with the top of the tram of the rail. The first method leaves an exposed edge of the paving surface, which is commonly subject to rapid wear, while the width of tram is sufficient to permit the wheels of vehicles to run in the grooves and to leave the track with difficulty.

Grooved rails are shown in Figs. 41, 45, 46, 50, and 51. There are many variations in the form of groove and lip designed to meet varying conditions of use. The full-groove rail, shown in Fig. 41, has a groove in the head usually from an inch to an inch and a quarter in width; and when the pavement is made flush with the top of the rail it presents no obstruction to traffic of the street, and as the groove is too narrow to admit the wheels of vehicles it forms the most desirable track for use with smooth pavements. It can only, however, be used where pavements are kept clean and in good condition, as the groove is otherwise easily clogged with dirt, rendering the operation of the railway difficult and expensive. This disadvantage is greater in cold climates where snow and ice are common during winter.

For the purpose of lessening the clogging of the groove, the form of the grooved rail is sometimes modified by sloping the lip and widening the groove at the top, as shown in Fig. 46 or, as shown in Fig. 50, by making the lip of a less height than the head of the rail, thus allowing the wheel-flange to clear the groove of dirt in passing. This latter form, however, has the effect of forming a track which retains the wheels of vehicles, as will any difference of elevation between the head of the rail and the pavement between the rails.

In Fig. 51 is shown a grooved rail with an exten-

sion of the lip intended to form a track for wheels of vehicles with a view to reducing the wear of the pavement which commonly takes place immediately inside the rails. When this lip is below the level of the railhead it is subject to the same objection as the side-bearing rail of forming a track which it is difficult for wheels to leave.

For paved streets, where the pavement is well kept, the grooved rail seems to be superior to any other, and is often required by municipal authorities, par-

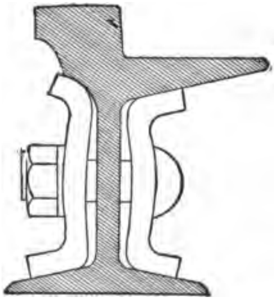

FIG. 49.

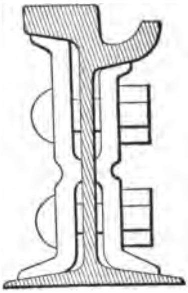

FIG. 50.

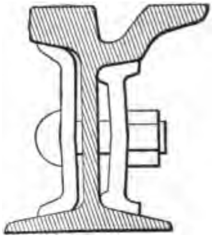

FIG. 51.

ticularly in the larger cities. For unimproved streets or on macadam or earth roads the tee rail is usually considered preferable, and may usually be employed with no more injury to the street traffic than any of the others, while possessing the advantage of economy both in cost and operation to the railway.

Joints and Fastenings. The solid construction of track is a matter of importance upon paved streets, because of the difficulty and expense of getting at the track to make repairs, as well as because of the disturbance to traffic when the pavement must be removed

for this purpose. The rail-joints and tie-connections are therefore matters requiring particular attention. Where no chairs are used, the use of tie-plates to form a bearing for the rail upon the tie, and to hold it securely in place, is to be recommended, and will greatly aid in forming a rigid track. There are a number of forms in use which give good results. They should be arranged to clamp the rail firmly and present a good bearing upon the tie. When chairs are used, they, like the tie-plates, should clamp the rail firmly and give good bearing surface. They should also be well braced for stiffness against lateral bending.

Joints, in the case of track formed of rails laid directly upon the ties, or upon wooden stringers, are usually made by placing a plate or channel-bar upon each side of the web of the rail-ends to be joined and bolting through. The use of slightly curved channel-bars fitting against the flanges of the rail, as shown in Figs. 49 and 51, seems to give good results, the spring in the channels serving to prevent the loosening of the bolts. This is the most common method of making joints. Fig. 50 shows a pair of ribbed-joint plates as used for high rails, the center bearing serving to prevent the buckling of the plates or the bending of the rail at the ends.

For track in pavements the rails may be laid to close joints, no allowance being necessary for change of temperature when the rail is fully bedded in the pavement.

A number of modifications of the above joints have been devised, some of them passing under the base of the rail and supporting it on the tie. Electrically welded or cast joints are also sometimes employed, consisting in welding a bar of steel on each side of the

end of the rail, or in casting an iron block about the ends to be joined, the casting being joined by means of the holes through the web of the rails.

Where chairs are employed to raise the rails above the ties, joints are frequently most satisfactorily made upon long chairs or bridges reaching across the space between two ties and forming a firm bearing for the ends of the rails.

In order to facilitate keeping the joints tight and enable the bolts at the rail-ends to be screwed up without taking up the pavement, joint-boxes are sometimes employed. These consist of openings with removable covers, giving access to the bolts at the ends of the rails.

On curves, guard-rails are commonly employed. Where tee rails are employed the guard is usually a second rail placed on the inside of the main rail, leaving only room for the wheel-flanges. In some instances, however, the guard is formed by bolting a flange to the main rail. For girder rails the guard is usually formed by the use of a rail in which the groove is wider and the lip heavier than common, and sometimes the lip extends somewhat above the head of the rail. Any difference of elevation of that kind is objectionable as producing unevenness in the pavement, but is frequently used as essential to the proper operation of the cars upon the curves.

Pavement in Car Tracks. The wear of a pavement is usually considerably increased by railway tracks upon the street. The extent of this wear depends upon the nature of the paving surface as well as upon the construction of the track. It is mainly the difference in resistance to abrasive wear between the rails and the paving surface which causes uneven and more

rapid wear of the pavement in vicinity of the track. A broken-stone surface, on account of its rapid wear, is particularly objectionable along a line of track, and is very difficult to keep in proper surface.

In case of narrow streets or rough side-pavements the use of the track for hauling heavy loads causes the cutting of the pavement upon the outside of the track, due to the gauge of trucks being greater than that of the track. This is especially the case where, owing to the use of side-bearing or center-bearing rails, the flange-grooves are wide enough to permit the wheels of trucks to enter them.

Where tracks follow country roads it is usually desirable, if possible, to place the track at one side and leave the center of the street free for the use of the ordinary traffic. When a broken-stone or gravel surface is employed it is common to lay planks on each side of the rail and bring the pavement against the planks, which materially lessens the obstruction offered to travel by the rails, as well as the difficulty of keeping the pavement in surface.

The methods of placing pavements in tracks depend upon the shape of the rail-heads and have already been discussed. Under heavy traffic when asphalt street surface is employed it is quite common to pave between the rails with stone or brick, and often to put a toothing of the same material outside the rails adjoining the asphalt. This serves to prevent the cutting of the asphalt along the rails. Sometimes when stone blocks are used in track the concrete base is omitted and the blocks are set on a gravel or broken-stone base. When such construction is employed the track should be very carefully ballasted and brought to an even bearing. There is always a tendency for

the track to work loose from the pavement and get out of surface, and under heavy traffic very firm construction is necessary to counteract this tendency.

ART. 101. TREES FOR STREETS.

It is always desirable, wherever possible, to have streets, at least those devoted to residential purposes, lined with rows of trees upon each side, both for the purpose of giving shade and to add to the beauty of appearance of the street.

The most satisfactory way of arranging trees is usually to have a tree space between the sidewalk and the curb in which the trees are planted in a straight line along the street. Sometimes in very wide streets a tree space or parking is arranged in the middle of the street with a driveway on each side. Trees should be spaced in the rows at such distances as will permit each tree when fully grown to spread to its full natural dimensions, which usually requires, for trees ordinarily employed, from 25 to 40 feet.

The selection of the variety of trees to be used for this purpose must of course depend upon climatic and local conditions. Those which rapidly attain their full size are usually to be preferred. They should have a graceful form and make a good shade, but the foliage should not be too dense. Evergreens are not generally desirable for this purpose. Where there is plenty of room for their development the large-growing varieties with light foliage are handsome and desirable. The size, however, must be suited to the space, and upon narrow streets, or where the trees are to be close to the buildings, they must be of small growth. The ease with which the tree may be grown and its

liability to disease or to be affected by the contaminations of a city atmosphere must be considered, as the conditions under which street trees must be grown are not usually favorable to their best development.

It is desirable, especially in cities of considerable size, that the planting and care of trees be under control of the municipal authorities. Trees may then be set with a view to the best general effect upon the street as a whole; the selection and planting of the trees may be properly done, and the trees after planting may be systematically cared for.

Art. 102. Selection of Pavements.

The selection of the best pavement for use in any given instance involves a study of the characteristics of each material as to its fitness for the particular service required, its suitability for meeting the local conditions under which it is to be used, and its probable cost. Local conditions must be taken into account, and it is not possible to lay down any fixed rules for universal application. The availability of materials in the locality, and relative costs which vary with local conditions, are frequently determining factors in the choice of pavements.

A good pavement should present a smooth, hard, and impervious surface, which may be easily cleaned and offers small resistance to traction. The comfort, convenience, and health of people using the street and of residents of the locality may be largely affected by the character of a street, and should be the first consideration in deciding upon an improvement.

HEALTHFULNESS.

The effect of a pavement upon the health of the residents of its locality will be affected by the tendency of the materials composing it to decay, by its permeability, and by its degree of freedom from noise and dust.

The permeability of a road surface is important on account of the tendency of surface water and refuse matter to penetrate and saturate it, and thus cause it to become dangerous to health. A continuous sheet pavement is the most desirable in this particular, and a block pavement with open joints the least so. When, however, the joints of a block pavement are properly cemented, the pavement may be made nearly impervious, and any of the pavements in common use, when well constructed, are practically impervious to water.

Noiselessness. The noise made by traffic upon a pavement is important not only because of its effect upon the comfort of the people using it or living adjacent to it, but also because to it are frequently attributed many nervous disorders to which people in some cities are subject.

Stone-block pavements are the most objectionable in this particular, causing a continual roar, due both to the rumbling of wheels over them and the blows of the horses' feet upon them. Upon asphalt the noise is only that due to the horses' feet, giving a sharp, clicking sound. Upon wood the horses produce no appreciable sound; but wheels give a dull rumble, generally considered the least objectionable of any of the noises made by the more common pavements. The noise of wood pavements is diminished by making the joints between blocks small, and a well con-

structured wood-block pavement is usually the least noisy of the pavements in common use. The noise made by traffic upon a brick pavement varies with the method of construction. The clicking sound made by horses is less than on asphalt, but the rumble of vehicles is greater, the rumble being usually more objectionable with hydraulic cement than with bituminous or sand-filled joints, although when proper expansion joints are used with cement joints the noise is not excessive.

Broken-stone roads are less noisy than any of the harder pavements excepting wood blocks, while earth roads are the most desirable on this account when in smooth condition.

Freedom from Dust. The dust arising from a pavement is objectionable on the score of health as well as of comfort. For the most part the dust found upon city pavements is produced from dirt carried there from the outside. To eliminate this it is necessary to keep the pavement clean, and perhaps to sprinkle it. All pavements produce more or less dust, even when kept thoroughly cleaned. Stone, brick, and asphalt surfaces all give off a small amount of very fine dust, which rises in the wind unless the surface is kept sprinkled. Wood-block surfaces are less objectionable on this account. Broken-stone roads wear rapidly and make dust freely in dry weather, unless kept sprinkled or treated with oil or tar (see Art. 41).

SAFETY.

The safety of a road surface depends upon the foothold afforded by it to horses under normal conditions, and also upon the degree of slipperiness that it may

take in wet weather, or under the influence of ice and snow in winter.

A dry earth road in good condition gives the best and surest foothold, with broken-stone and gravel roads nearly as good.

The relative safety of the various pavements used in city streets is a matter upon which there is considerable difference of opinion amongst authorities. Local conditions affect the pavement in this regard to an important degree. The dampness of the climate, the shade from buildings, the cleanliness of the streets, and the prevalence of snow and ice in winter are all important.

Statistics upon the question of relative safety of wood, asphalt, and granite have been collected by Captain Greene in this country and by Colonel Haywood in London, the attempt being made to determine the number of miles traveled by horses upon each kind of pavement to each accident due to slipperiness.

The results of Colonel Haywood seem to show that of the three, wood is the safest and granite the most dangerous, while the results of Captain Greene show asphalt to be the best and wood the worst in this particular.

Colonel Haywood's observations were all taken on London streets, and are as follows:

	Miles Traveled to Each Fall on —		
	Granite.	Asphalt.	Wood.
In dry weather	78	223	646
In damp weather	168	125	193
In wet weather	432	192	537
All observations	132	191	330

The observations were made when dry weather prevailed, and therefore are somewhat unfavorable to granite, which is safest when wet.

Captain Greene's observations were made in several American cities, and showed the distance traveled to each fall to be, on granite 413 miles, on asphalt 583 miles, and on wood 272 miles. The observations on wood in this series were too few to give a reliable indication, and it is to be observed with regard to all of them that slipperiness is largely affected by the condition in which the surface is maintained, and it is therefore difficult to draw any general conclusions which would fit all cases.

All hard pavements are slippery when muddy and wet, and cleanliness is the necessary condition of safety.

Wood and asphalt, if clean, are least slippery when dry and most so when simply damp. Granite, after the surface becomes worn and polished, is most slippery when dry and least so when wet.

Under a light fall of snow both wood and asphalt become very slippery, and in freezing weather wood sometimes becomes slippery through the freezing of the moisture retained by it.

No statistics are available as to the safety of brick pavements, but it is thought a desirable material in this respect.

It may also be remarked that the danger of a horse falling upon any pavement depends very largely upon the training of the animal and whether he be accustomed to the particular surface in question.

DURABILITY OF VARIOUS SURFACES.

The durability of a road or pavement is dependent upon so many circumstances connected with local conditions, the nature of the traffic, methods of construction, and efficiency of maintenance, that any comparison of the various kinds of pavement in this respect is difficult and likely to be misleading.

The qualities which especially affect the durability of the road may be partially enumerated as follows:

(1) The hardness and toughness of the material composing the surface, upon which depends the resistance of the surface to the abrading action of the wheels and horses' feet passing over it.

(2) The firmness of the foundation, which serves to distribute the loads over the road-bed and keep the surface uniform.

(3) The drainage of the road-bed, which can only properly sustain the loads which come upon it when it is dry.

(4) The permeability of the surface, which should form a water-tight covering to serve the purpose of keeping the foundation and road-bed in a dry condition.

(5) The resistance of the materials of the pavement to the disintegrating influences of the atmosphere and to the action of the weather.

The relative importance of these various factors, in any particular case, depends largely upon the nature and extent of the traffic which is to pass over the pavement.

The amount of traffic to which a street is subjected is usually estimated in terms of tons per foot of width of street, by observing the number of teams passing a

given point during certain times, classifying them, and assigning an average value of load to each class. The wear of the surface will naturally be somewhat proportional to the amount of traffic. The life of a pavement is, however, affected by other conditions, and hence cannot always be inferred from the amount of traffic.

Traffic may also be classified according to its nature as heavy or light, depending upon the weight of individual loads which are carried. It is the heavy loads borne upon narrow wheel-tires that do the greatest damage to a pavement, and hence the nature rather than the amount of traffic determines the character of pavement necessary.

Granite blocks, where a firm unyielding foundation is employed, give the hardest and most durable surface of any of the common pavements. This is epecially the case under very heavy loads.

The durability of wood-block pavements under wear varies widely for the different types of construction. The better grades of treated wood-block pavement seem to have given results, in some instances, second only to granite blocks, and they are being used under some of the heaviest traffic in the larger cities. The older and cheaper types of wood pavement are inferior in wearing qualities to brick or asphalt.

Asphalt and brick pavements when well constructed are satisfactory under any but the heaviest traffic. The relative durability under wear of brick and asphalt is a matter of doubt, both materials being subject to considerable variations in quality, and showing varying results in different localities, due both to differences in the quality of the material and in the methods of construction. Bitulithic may be classed with asphalt

as to durability, although it seems in some instances to have shown greater resistance to wear than ordinary asphalt.

Broken stone wears rapidly under moderately heavy traffic, and should be employed only on suburban streets or country roads used mainly for light driving or a small amount of traffic.

Art. 103. Sources of Revenue for Street Improvement.

Funds required for the improvement of streets in cities are commonly derived either from general taxes, from assessment upon property in vicinity of the improvement, or from a combination of the two. In some instances also special taxes are levied upon vehicles, or upon business interests which make large use of the streets, for the benefit of the paving funds.

Mr. J. L. Van Ornum has brought together* data showing the practice in fifty American cities. In a few of these the whole charge is placed upon the general taxes. In a few, the whole charge is laid upon adjoining property, while in a larger number the cost is distributed between the two in varying proportions. Some cities pay for the intersections of streets from general taxes, laying the whole cost in the blocks upon property fronting the street. Some also pay a share (about 20 per cent to 40 per cent) of the cost between intersections from general taxes; while in other instances the city pays a fixed percentage of the whole cost, the remainder being assessed upon the property benefited. Some cities pay for the grading of the street from general

* Transactions American Society of Civil Engineers, Vol. XXXVIII.

funds, while others include the grading in the cost of paving and assess it upon the property.

There has been considerable discussion on the part of municipal officers concerning the proper method of apportionment, and many different opinions have been advanced as to what should be required in fairness to all of the interests involved. Some contend that the streets are for general public use, and that the people of the city as a whole should pay for their improvement, thus ignoring the advantage that the improvement of streets may be to the owners of abutting property in the increase of values. Others insist that it is fair to tax the whole of the improvement upon abutting property, claiming that the main benefit is to that property, and that when improvement becomes general each will have paid his proper proportion of cost. Between these two extremes are the larger number who recognize the interest of both parties and advocate the division of cost between the city as a whole and the abutting property in varying proportions. Opinions differ as to what these proportions should be, and it is evident that the public interest in some streets of a city is much greater than in others. Some streets are main arteries for travel, others but very little used, and the relative values to the general public and to the property owner are very different in the two cases.

It would be quite impossible to devise any general method of apportioning the costs of street work among the various interests involved in such a way as to tax each in proportion to the benefit derived from the improvement. It is generally recognized that the city as a whole is interested in the improvement of its streets and also that property in the immediate vicinity of an improvement is directly benefited thereby. Therefore

it may be considered fair and reasonable to tax either or both for the improvement. A division of cost would without doubt be the more equitable method, but the feasibility of securing necessary funds for proper improvement by one method or the other must be the determining factor in selecting the method. In some instances where the funds derived from general taxation are closely limited, the assessment of the whole cost of street improvements upon abutting property makes possible an extent of improvement which would otherwise be out of the question, with manifest advantage to the property taxed.

In assessing the cost of street improvement upon property in the locality of the work, the usual method is to apportion the cost upon abutting property in proportion to the frontage upon the street improved. Frequently the apportionment is made in proportion to area on each side of the street within a certain distance of it (sometimes half a block). In a few instances a combination of the two methods is used, by which a portion of the cost is assessed upon abutting property in proportion to frontage and the remainder upon area within certain distance. The frontage assessment seems reasonably fair and is most commonly employed.

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